Oceanus

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Oceanus®

The Magazine of Marine Science and Policy
Volume 26, Number 2, Summer 1983

Paul R. Ryan, *Editor*
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Buoy work on the R/V *Knorr.* Photo by R. J. Bowen, WHOI.

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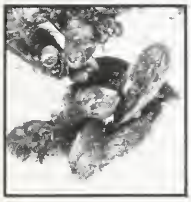

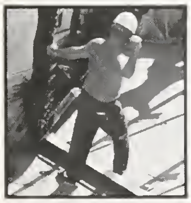

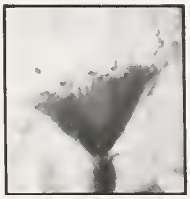

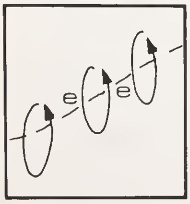

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comment

In the Winter 1982/83 issue of *Oceanus* on "Marine Policy for the 1980s and Beyond," there was a call for the establishment of a new commission, patterned after the Stratton Commission of 1966, to study the implications of the Law of the Sea Convention in view of the United States' refusal to approve the Treaty. We are pleased to report that the call — issued by many in the marine community, including Paul M. Fye, president of the Woods Hole Oceanographic Institution, and Robert W. Knecht and Robert E. Bowen, two fellows in the Marine Policy and Ocean Management Program at the Institution — has been answered.

On May 2, 1983, Walter B. Jones, Democrat of North Carolina and Chairman of the House Committee on Merchant Marine and Fisheries, introduced a bill (HR 2853) on behalf of himself and 17 co-sponsors to establish a National Oceans Policy Commission. A similar bill (S 1238), sponsored by Claiborne Pell, Democrat of Rhode Island, and Ernest F. Hollings, Democrat of South Carolina, was introduced in the Senate on May 9.

In introducing the House bill, Jones stated that "U.S. ocean policy is now in a period of fundamental transition. Internationally, the decision of the United States to terminate further direct participation in the Convention on the Law of the Sea generated a wide range of international marine issues directly affecting our important national strategic and resource interests. While the Presidential Proclamation of an Exclusive Economic Zone on March 10, 1983 (see page 67), capsulized the basic jurisdiction of the United States, many specific issues relating to navigation, fishing, marine pollution, marine scientific research, vessel source pollution, and the continental shelf remain."

The Commission would be charged with the responsibility of making recommendations to define and implement a national policy based on five principles, which are:

- Encourage the development of international oceans law in a manner that will promote the peaceful uses of the oceans and balance the interests of the United States and all nations;
- Encourage and promote the United States' continued leadership in research, conservation, management, and development of marine resources;
- Promote the wise use and compatible development of living and non-living marine resources;
- Encourage U.S. investments in the exploration and development of marine resources and technologies; and
- Ensure the equitable allocation of responsibilities and fiscal resources for marine resource activities among the various levels of government and the private sector.

The 15-member Commission created by the House legislation would be composed of three representatives from federal agencies appointed by the President, three representatives of non-profit organizations, five representatives from commercial groups, two coastal state governors, and two ocean policy specialists from the academic community. The Senate version of the bill varies slightly from the House version in its provisions for Commission membership, and the final makeup of the body will be the subject of compromise before enactment.

The bill would authorize $1.5 million for each fiscal year to support the work of the Commission, which would report its recommendations to the President and Congress at the end of two years. It also would be required to issue an interim report one year after date of enactment on "the international oceans policy issues associated with areas under coastal state resource jurisdiction." The Commission's work would end 30 days after its final report.

On May 17, Jones opened full committee hearings on the legislation. All three witnesses on the first day of the hearings agreed that the timing is right for establishment of the Commission. Among those testifying on the "National Ocean Policy Commission Act of 1983" was Dr. Fye. He spoke of the issue "closest to my heart" — marine research:

"I, like many other oceanographers not only in the United States but from other nations as well, had hoped that the freedom to conduct scientific research in the entire ocean could be a part of a new body of legislation concerning the oceans. In spite of valiant efforts on the part of the U.S. Delegation but with little support from other delegations we now find ourselves at the mercy of other nations for access to better than 30 percent of the ocean waters, in that the consent of a coastal state is required before a research ship can undertake research in their economic zones. While I regret this, it is a new regime which oceanographers must learn to live with.

"Ocean phenomena do not stop at national boundaries, or stop at the edge of the continental shelf. Scientific curiosity does not cease as one moves from deep water to shallow water or from one area of the deep sea into the economic zone. In my opinion, one of the prime challenges to the new Commission is to see that scientific research from U.S. research ships will continue to flourish. Here, indeed, the United States has been a world leader, and we must remain so."

* * *

In a related development, the Marine Policy and Ocean Management Program at the Woods Hole Oceanographic Institution has received a grant from The William H. Donner Foundation to plan an Ocean Policy Roundtable. The Roundtable will provide a nongovernmental forum for debate on key ocean policy issues. Members will be selected from public interest and environmental groups, industry, academic and research institutions, and others with an interest in ocean policy affairs. The first meeting is scheduled for late October, 1983.

Paul R. Ryan

The winter of 1982-83 brought several damaging storms to southern California. Scenes like this will be more common in the future if the expected rise in the atmospheric carbon dioxide content causes sea level to rise. (Los Angeles Times *photo)*

The Oceans and the Carbon Dioxide Problem

by Roger Revelle

Earth is unique among the planets in its possession of an ocean — the large mass of water that covers most of its solid surface. But the water might not be liquid if it were not for the presence in Earth's atmosphere of a relatively small quantity of carbon dioxide (CO_2). This colorless, odorless gas acts as a one-way radiation screen. It is transparent to visible light, where most of the energy of sunlight is concentrated, and it absorbs and reradiates some of the longer-wavelength infrared radiation that would otherwise escape from Earth to space. Consequently, more infrared radiation must be emitted from near the surface, and the near-surface temperature must be higher, to maintain a balance between incoming and outgoing energy. Water vapor in the air behaves in a similar fashion to carbon dioxide, as do methane and other "greenhouse" gases that are present today in very low concentrations. In the absence of carbon dioxide and water vapor, the surface temperature would be well below the freezing point of water, and the oceans would be a solid mass of ice.

An even more unpleasant situation would exist if there were no ocean. Over geologic time, vast quantities of carbon dioxide have been released from Earth's interior by volcanoes. This release is still occurring at an estimated rate of about 40 million tons of carbon per year. During the past several billion years, at least 50 million gigatons (a gigaton is a billion tons) of carbon as carbon dioxide have entered the atmosphere. If this quantity had remained in the air, there would have been a "runaway" greenhouse effect, and the temperature at Earth's surface would be several hundred degrees Celsius. This is exactly the situation on Venus, which has had no ocean for a long time, and may never have had one. The Venusian atmosphere is heavier than Earth's and consists mainly of carbon dioxide; the surface temperature is a hellish 400 degrees Celsius.

Because most of the water on Earth is liquid, nearly all the tens of millions of gigatons of carbon dioxide gas that have entered the atmosphere from volcanoes have been transformed into carbonates and bicarbonates in the weathering of silicate rocks, or have combined with water, nitrogen, and a few other substances to form the tissues of photosynthetic plants. The weathering products and the remains of the plants have been deposited mainly in the sediments of the ocean floor, and are now found in the sedimentary rocks derived from them, as calcium and magnesium carbonates and organic materials. Only about 700 gigatons of carbon remain in the air; about 38,000 gigatons are dissolved or suspended in seawater as carbonate and bicarbonate ions and "organic carbon"; and around 2,000 gigatons are present in the living biota on land, mainly in forest trees and soil humus. Because nearly all the carbon that has entered the atmosphere has been sequestered in marine sediments, our atmosphere exhibits only a mild "greenhouse" effect. Moreover, the preservation of reduced organic carbon in the sediments and sedimentary rocks has permitted a large fraction of the oxygen produced in photosynthesis to remain uncombined in the air, thereby providing a necessary condition for animal life, including our own, with its high-intensity metabolic energy demands.

The Buildup

A very small part of the reduced organic carbon in marine and freshwater sediments has been transformed into the "fossil fuels" — coal, petroleum, and natural gas — that power industrial civilization. When these fuels are burned, carbon dioxide is re-formed in the atmosphere. On the order of 5,000 gigatons of carbon in recoverable fossil fuels have accumulated in sedimentary rocks during the past half-billion years. These are now being used up in a few short human generations. The rapid influx of carbon dioxide to the atmosphere from fossil fuel combustion, starting about 120 years ago, is one of the two main causes — the other being the clearing of forests for agriculture and other uses — of the present buildup of atmospheric carbon dioxide.

This buildup has been well documented since the International Geophysical Year of 1957-58, when Charles David Keeling of the Scripps Institution of Oceanography began what has now become one of the best known and scientifically most influential geochemical time series ever made. Keeling installed two recording infrared-absorption CO_2 analyzers — one near the top of Mauna Loa on the island of Hawaii, the other at the South Pole. A nearly continuous record of atmospheric CO_2 content at these two locations has been made with high accuracy ever since, and is still continuing. During these 25 years, other workers have established similar measuring stations in many places, ranging in latitude from Barrow, Alaska, to Halley, Antarctica, and in environmental conditions from Western Europe to weather station PAPA, in the center of the North Pacific, to Amsterdam Island in the South Indian Ocean. The records from most of these stations, particularly those in the Northern Hemisphere, exhibit a significant seasonal variation in the atmospheric CO_2 content, resulting from differential rates of photosynthesis and respiration by land plants at different seasons of the year. All the stations show an increase in carbon dioxide from year to year, which has recently been a little more than one part per million by volume (ppm) per year.

The average atmospheric carbon dioxide content at Mauna Loa increased from 315.8 ppm in early 1959 to 341.2 ppm in January of 1983, a rise of 8 percent, corresponding to 53.5 gigatons of carbon. During this period, 94.5 (±5) gigatons of carbon from fossil-fuel combustion were injected into the atmosphere as carbon dioxide. Rather shaky

The combustion of fossil fuels, as on this Los Angeles freeway, is another cause of rising carbon dioxide levels in the atmosphere. (Los Angeles Times *photo)*

Large tracts of forest are cleared by fire in Brazil for new pastureland. The removal of forests boosts the amount of carbon dioxide in the atmosphere, since trees incorporate from 10 to 20 times more carbon than do crops or grasses. (Photo by Richard O. Bierregaard, World Wildlife Fund)

estimates indicate that between 20 and 50 gigatons were produced from partial or complete clearing of forests and woodlands and oxidation of part of the underlying soil humus. Thus the "airborne fraction" — the proportion of anthropogenic carbon dioxide remaining in the air, relative to that injected by human actions — is between 37 and 47 percent.

The modern age of rapidly increasing atmospheric carbon dioxide is more or less arbitrarily assumed to have begun in the middle of the 19th century, when human populations and the use of fossil fuels began to grow at accelerating rates. Unfortunately, there are few useful measurements of atmospheric carbon prior to 1958. Fossil-fuel carbon dioxide produced between 1860 and 1958 has been estimated by Ralph Rotty of the Institute for Energy Analysis in Oak Ridge, Tennessee, as corresponding to 76.5 gigatons of carbon. There is a wide range of estimates, by various authors, of the amount of carbon released during the past 120 years by human activities in forests and woodlands. George M. Woodwell of the Marine Biological Laboratory in Woods Hole, Massachusetts, and his collaborators have estimated this to be about 180 gigatons, somewhat more than the total fossil-fuel carbon released. Agricultural historian J. S. Richards of Duke University in Durham, North Carolina, using available historical data for all countries on land-clearing for agriculture, plus estimates for other forest destruction, believes that at least 120 gigatons of carbon have been released. We may conclude that between 290 and 360 gigatons of carbon have been injected into the atmosphere since 1860. Using the minimum figure and assuming an airborne fraction of 47 percent, the amount of anthropogenic carbon remaining in the air corresponds to about 65 ppm. With an airborne fraction of 37 percent, the maximum figure is 62 ppm. Atmospheric carbon dioxide probably has increased by about 23 percent during the last 120 years.

Where It Goes

An important question is: What has happened to the other 53 to 63 percent of the carbon injected into the air? Some of this "lost" carbon has certainly been absorbed by the ocean and some has probably been

Uplifted coral reef terraces on the coast of Papua New Guinea are evidence of former sea levels. (Photo by Arthur L. Bloom)

taken up in the biosphere. The ocean contains 53 times as much carbon dioxide as the atmosphere, and, at first thought, it would seem reasonable that it could easily take up the relatively small amounts of carbon dioxide introduced by human activities each year. However, most of the carbon in the ocean is present as carbonate and bicarbonate ions, and very little as free carbonic acid. Because of the interactions between these three carbon dioxide species, a change of atmospheric carbon dioxide pressure of, say, 10 percent will result in only a 1-percent change in the carbon dioxide content of the mixed ocean layer, which rapidly exchanges carbon dioxide with the air. Transfer of carbon dioxide to greater depths depends on the slow processes of vertical mixing, convection, and advection along surfaces of constant density. The behavior of "transient" tracers such as tritium and carbon-14, produced by the atomic weapons tests of the 1950s and early 1960s, indicates that the added carbon dioxide has probably penetrated only a few hundred meters beneath the sea surface.

The many workers who have studied this problem have variously calculated that between 22 and 47 percent of the anthropogenic carbon dioxide has been absorbed in the ocean, with the range of most probable values being between 30 and 40 percent. It is hard to escape the conclusion that 10 to 30 percent of the carbon dioxide injected into the atmosphere, at least during the last few decades, has been absorbed in the biosphere.

Carbon dioxide acts as a fertilizer for land plants; hence higher atmospheric CO_2 content should lead to increased photosynthesis, and probably to increased carbon storage in the land biosphere, provided other factors necessary for plant growth, including sunlight, phosphorus, nitrogen, and water, are present in sufficient amounts. Perhaps even more important is the fact that, in a CO_2-enriched atmosphere, plants require less water for the same biomass production because evapotranspiration from leaf surfaces is reduced. Consequently, more plant growth can be expected at times and places where water supplies are deficient.

Although there is little direct evidence, there is some suggestive indirect evidence of a biosphere response to higher atmospheric CO_2 during recent years. At Mauna Loa, weather station PAPA, and Barrow, Alaska, the amplitude of the seasonal swings in atmospheric CO_2 is apparently increasing by about 0.65 percent per year, probably representing an increase in both photosynthesis and respiration and implying an increase in biomass. Part of this increase may be due to reforestation in the United States, China, and Europe, but as much as half could come from a growth of biomass in previously existing forests and woodlands. The net increase in biomass could be on the order of one gigaton per year.

An alternative hypothesis is that biological activities in the ocean may somehow be extracting carbon dioxide from the air. Wallace Broecker of the Lamont-Doherty Geological Observatory in Palisades, New York, has concluded that about 8 percent (close to 2 gigatons) of the organic matter produced by photosynthesis in subsurface waters sinks into the depths, where most of it is oxidized to carbon dioxide and water. This process is balanced by a slow upwelling of deep waters with higher carbon dioxide content into the surface layers. The deep ocean waters contain 5 to 10 percent more carbon dioxide than they would if they were at equilibrium with the partial pressures of carbon dioxide in the atmosphere. The combination of biological and gravitational processes can be thought of as a pump that maintains a high carbon dioxide content in deep water and a low content in surface waters and the atmosphere. If the pump ceased to act, atmospheric carbon dioxide would eventually increase several fold. Conversely, if the pump were more effective, atmospheric carbon dioxide would become depleted.

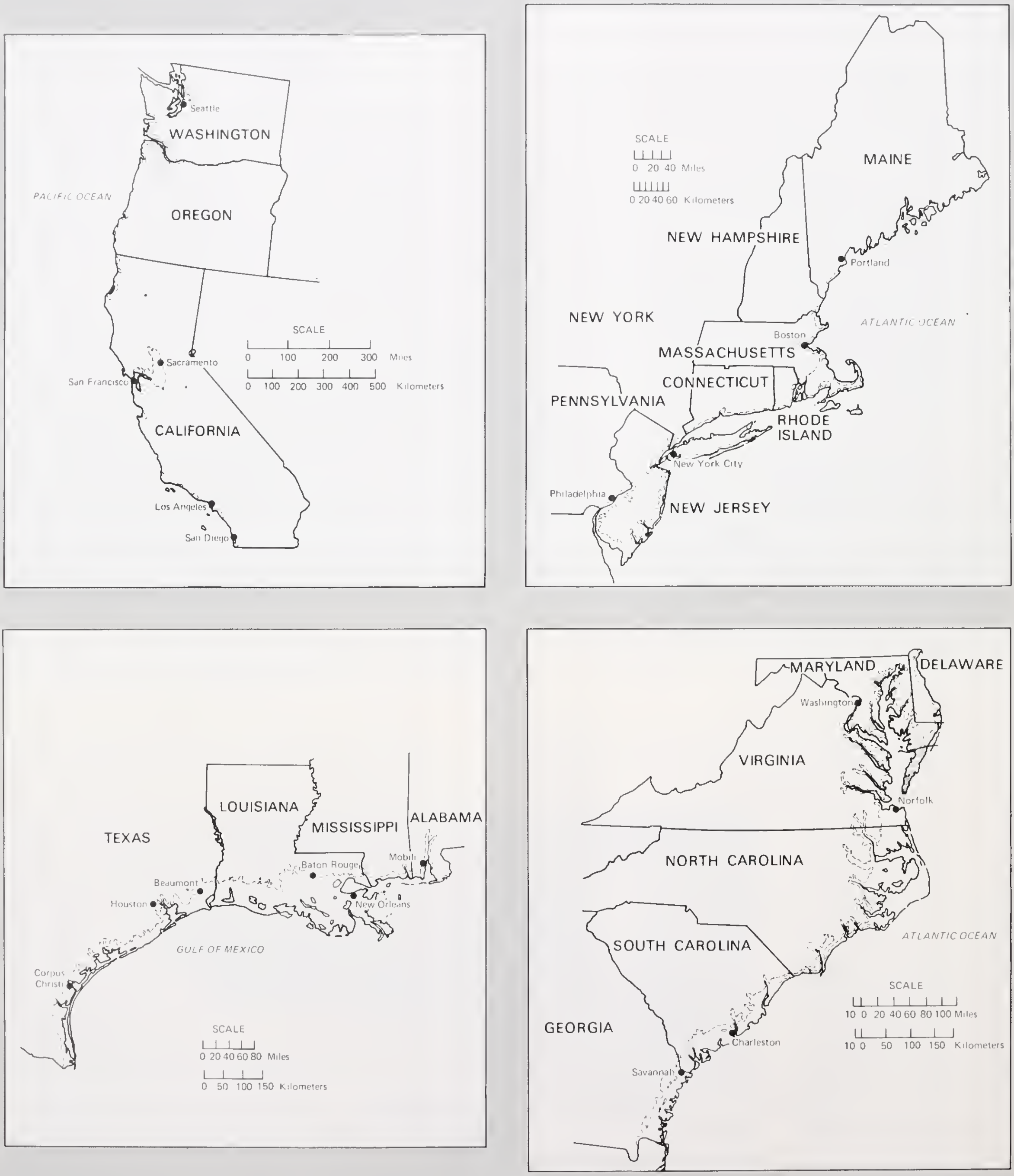
Some increase in photosynthetic activity in the near-surface ocean waters and a consequent increase in the efficiency of the downward-acting CO_2 pump may have occurred in recent decades. This would be the result of an increased supply of nitrogen and phosphorus from rivers, due to the much greater use of fertilizers in modern agriculture. However, this process is probably insufficient to cause the estimated depletion of atmospheric carbon dioxide.

Historical Variations

Variations in the effectiveness of the oceanic carbon dioxide pump probably brought about the marked variations in atmospheric carbon dioxide during the last 30,000 years that have been demonstrated by Hans Oeschger and his colleagues at the University of Bern, Switzerland. These workers analyzed air trapped in glacial ice in Greenland and Antarctica and found carbon dioxide variations of between about 175 and 300 ppm over times on the order of 1,000 years. The rises and falls were quite abrupt, occurring in 100 or 200 years. These variations may be due to alternate speeding up and slowing down of ocean upwelling and turbulence processes that transport essential plant nutrients into the subsurface photosynthetic zone, with resulting increases and decreases in the effectiveness of the biological pump. Alternatively, the changes could have been caused by variations in the supply of nutrients from land and from the sediments of the continental shelf, under the rapidly changing conditions of the Ice Age. Oxygen isotope analyses of the ice indicate that temperatures rose by 4 or 5 degrees Celsius when the atmospheric carbon dioxide was high, compared with times of low carbon dioxide content.

Thus far we have said little about the effects of changing levels of atmospheric carbon dioxide on the ocean. Estimates based on climatological models of the general circulation of the atmosphere are that a doubling of atmospheric carbon dioxide, which can be anticipated during the next 100 years, would cause a rise in global atmospheric temperature of between 2 and 3 degrees Celsius, with the change in temperature at high latitudes perhaps three times that near the equator. Temperatures at the surface of the ocean would rise by an equal amount, and significant warming would progress downward more

This notch on Little Sale Cay, in the Bahamas, is 6 meters above sea level. It was probably formed about 125,000 years ago by boring and browsing organisms before the onset of the last ice age. Suspended here in its original form, it provides an intriguing clue that sea level fell from this position too rapidly for the notch-forming process to keep up. A slower rate of fall would have caused erosion of the whole cliff. (Photo by A. Conrad Neumann)



The dashed lines delineate areas that would be flooded if sea level were to rise 7.6 meters (25 feet). (Maps by Robert S. Chen, University of North Carolina) than several hundred meters. The heat transferred to the ocean would slow down the atmospheric temperature rise by several decades, but it also would result in a small positive feedback of heat, because the higher ocean temperatures and the corresponding decreased solubility of CO_2 would release carbon from the ocean into the atmosphere. This feedback would result in a further atmospheric temperature rise on the order of .5 degrees Celsius.

Models of the ocean/atmosphere system are not sufficiently developed to predict the changes in ocean circulation that might result from the warming of the ocean and the atmosphere. But one result is clear. Oceanic warming would cause an increase in ocean volume due to thermal expansion and, probably, some melting of the Greenland and Antarctic ice sheets and alpine glaciers. Calculations indicate that the rise of sea level could be at least 60 centimeters during the next 100 years. This is at least four times the present rate of rise, which is about 15 centimeters per century.

Warming of the ocean waters around Antarctica could result in a thinning of the Ross and Filchner-Ronne ice shelves and the subsequent disappearance of the West Antarctic ice sheet. This ice sheet is believed to be inherently unstable because most of it is below sea level; it probably disappeared during the last interglacial period. Such a disappearance would bring about a rise in sea level of about 5 meters, perhaps during as short a time as 500 years, or about 1 meter per century.

Terraces 5 to 6 meters above present sea level exist in many parts of the world. Their time of formation has been dated at about 120,000 years ago, at the peak of the last interglacial period. Oxygen isotope ratios in deep-sea cores show that ocean salinity was somewhat lower at that time, as it would be if the volume of the ocean had increased by about 2 million cubic kilometers — equal to the mass of the portion of the West Antarctic ice cap that is now above sea level, and the freshwater ice below sea level.

Another positive feedback might occur because of the release of methane from the sediments of the continental slope as the ocean warms. Methane is a potent "greenhouse" gas, and a doubling of the present atmospheric content of about 5 gigatons would cause a rise in average atmospheric temperature of between .5 and 1 degree Celsius. It probably exists in the sediments of the continental slope below depths of 300 to 600 meters in the form of a "clathrate," that is, a methane-water ice. The estimated quantity of methane in this form is very large, on the order of 10,000 gigatons.

Warming of the ocean could result in an annual release of methane from these continental slope clathrates of about .6 gigatons. The atmospheric residence time for methane is 5 to 10 years, and therefore the quantity of methane in the air could rise by 3 to 6 gigatons, 2/3 to 4/3 of the present amount. This quantity would be in addition to most of the present rate of increase of atmospheric methane from other sources — about 7 gigatons per century. The corresponding increase in global average surface temperature could be between .65 and 1.8 degrees Celsius. An extensive sediment sampling program should be undertaken to determine the depth, thickness, and distribution of methane clathrates on the continental slopes throughout the world.

Thus far we have concerned ourselves with the next 100 years, which is a long time on a human scale. But we can also ask, What about the next 1,000 years? What will happen to the excess carbon dioxide remaining in the atmosphere 100 years from now? Part of it will be absorbed gradually by the oceans, but between a quarter and a third will still be in the atmosphere after 1,000 years. Unless other forces intervene, mankind can look forward to a warm climate for a long time to come.

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In Pursuit of Oceanography and a Better Life for All

by Charles D. Hollister

From weather to whales, from fluid physics to ecology, the science of oceanography is an interweaving of disciplines that has given us an understanding of our watery planet. Although its pioneers are now retiring, a vast frontier awaits the next generation.

For the student considering a career in science, oceanography offers the opportunity to apply new discoveries to important human and environmental problems. Through the use of high technology to study the ways the oceans interact with the atmosphere, the land, and the seabed, oceanographers of the future will help determine the quality of life and will provide a basis for the laws that will safeguard it. It is a challenge that can yield tremendous satisfaction.

Recently there have been very exciting breakthroughs in each of the major subfields of oceanography, and each is alive with new questions. For example, vertical stirring of ocean waters is thought to be much slower than horizontal stirring, but quantitative predictions still elude us. This uncertainty, of course, casts doubt on the accuracy of certain predictions regarding the disposal of hazardous wastes in the ocean and some important aspects of commercial fisheries management.

Vents spewing very hot water laden with nutrients and minerals have been discovered on the floor of the deep sea. Surrounded by previously unknown organisms, these vents have profoundly affected our ideas about the necessity of sunlight for life-giving processes, and even our ideas about evolution. Another puzzle is what appear to be high-energy deep-sea storms, which redistribute enormous amounts of sediment across the abyssal seafloor. These are just a few examples of basic research problems that need to be solved.

Preparations, Expectations

The best undergraduate preparation for an oceanographer is rigorous training in applied mathematics, physics, chemistry, geology, biology, and engineering. Regardless of the subfield a student eventually chooses to specialize in, a broad background in the basic sciences, stressing

Graduate students studying sand transport off Cape Cod, Massachusetts. (Photo by Vicky Cullen, WHOI) mathematics, and some experience with computers should enable him or her to follow curiosity as it crosses the traditional barriers between disciplines.

Some oceanographers will naturally go to sea on research vessels in order to obtain the information needed to solve their research problems, while some will get their data in the form of signals transmitted from satellites, stored on magnetic tape, and read by computers. Still others will use the computer for modeling idealized situations. The modeling exercise can be an early step toward determining which data are actually needed for solving a particular problem. What all oceanographers seem to share is an intense commitment to research, an ability to extract the maximum amount of information from any project, and the drive and confidence to complete the tasks they initiate.

There are four major fields of employment for people with training in oceanography. Academic positions involve varying proportions of teaching and research; teaching salaries are covered by the institution while research is supported by grants and contracts generated by the scientist. Academic positions offer the most freedom to control personal time and direction of research, but they pay less than other jobs in the field. Industry jobs usually offer the highest salaries, but time and research activities are more closely constrained. Consulting also pays well, but requires a high investment of energy and time to generate and complete projects, especially if one is self-employed. Finally, federal and state employees generally do both applied and basic research, much of it involving the writing of data reports and environmental impact statements. Government jobs offer more job security, with intermediate salaries.

A bachelor's degree in any of the basic sciences is enough for a job as a technician or research assistant. The master's degree is sufficient for some mid-level professional jobs in government, consulting, and industry. However, a doctorate is a must for those who go into the academic field, or become directors or managers in the other areas.

Today the greatest demand is for geophysical/geological and physical oceanographers, as well as oceanographic engineers. Presently, chemical and biological oceanographers are in less demand, but future career conditions cannot be predicted with any certainty. In fact, scientific emphasis and job priorities may even change during the course of a student's graduate education. For example, when the Organization of Petroleum Exporting Countries (OPEC) raised oil prices, the demand for geologists immediately rose. Society's need for information can drive the demand for Ph.D.s. All things considered, it is best to simply follow one's own curiosity.

The Subfields of Oceanography

Marine Geology and Geophysics

This is one of the most interdisciplinary of the natural sciences. Fluid motions, chemical reactions, and living organisms all affect the sedimentary record of the seafloor. Strain, pressure, heat, and chemical gradients determine the composition, distribution, and interrelationships of rock types below the sediment. Both the geologist and the geophysicist propose and test hypotheses about the earth at and below the seafloor, aided primarily by remote sensing methods. Both need training in applied mathematics and computer methods. The marine geophysicist searches for anomalies, such as unexpected strengths or weaknesses in the local gravity or magnetic field.

Oceanographers must use many pieces of information to narrow the range of possible explanations for the formation of the earth and the processes acting on it. For example, the hypothesis that the "ribs" of solid earth beneath the sea are formed at spreading centers and lost beneath convergent plate boundaries (the plate tectonic theory) was made plausible by remotely sensing magnetic fields, mapping sediment distributions through seismic reflection profiling, and analyzing earthquake motions; but the final confirmation, or "ground truth," came from the samples of deep-sea sediment brought up by the drilling ship *Glomar Challenger*.

The marine geologist's research focuses on the tectonic, volcanic, and sedimentation processes that determine the shape of the seafloor. Special attention is now being given to divergent plate boundaries, along which heat and chemicals escape from deep within the splitting earth. The attempt to understand the physical, chemical, microbial, and geological processes of this new alchemy will steer research for at least the next several decades. The geologist also strives to understand the fossil record, which can reveal historical changes in climate and the

A student at WHOI learning that mathematics is important in oceanography. (WHOI photo)

oceanic environment caused by the shifting of continent and ocean over the earth's surface.

Although geology and geophysics can be separated, most successful researchers in these disciplines try to maintain a "twin perspective." An impressive new generation of marine geological and geophysical research tools has just recently emerged and promises to open up a whole new scale of seafloor investigations.

Of a more practical nature is the marine geology subfield of estuarine, coastal, and continental shelf geology. The edge of the sea, greatly influenced by tides and storm waves, is poorly understood. Industry and government both spend vast sums of money on projects there, often with disastrous results.

Oceanographic Engineering

The increasing sophistication of oceanography, especially within the last decade, has led to an unprecedented demand for special engineering knowledge and skills. The field of ocean engineering has evolved in response to growing interest in the use and defense of the oceans. It is a complex hybrid of many of the classical engineering disciplines, such as electrical, mechanical, civil, chemical, and marine engineering. Its challenging problems require creative combinations of a wide range of ocean science and engineering principles.

Some ocean engineers apply their talents to instrument design in order to measure physical processes and thus answer basic scientific and engineering questions about the ocean environment. Such equipment must function in the salty, heavy, and corrosive ocean, an environment that is more hostile than outer space.

Space-age technology that has been transferred to ocean engineering is likely to lead to fundamental discoveries. Wind and wave patterns, chlorophyll distribution, and surface temperature can all be mapped using satellites. Measurement systems that use satellites to transfer data from unmanned instruments far out at sea are being designed, and some already have been deployed. Problems associated with sound transmission in the sea also challenge the ocean engineer.

With the rapidly increasing exploitation of ocean resources, engineers are currently planning systems that could generate electrical power at sea, by taking advantage of the temperature differences between water near the surface and water at depth or by using the energy of tides and waves. Systems that operate under extremely high pressure will be needed for mining manganese nodules or polymetallic sulfides on the ocean floor. Fossil fuels and minerals, needed by our growing society, must be obtained from the ocean safely, economically, and without environmental degradation. Designing offshore platforms that will extract oil efficiently and remain safe during winter storms requires engineers versed in structural designing, chemistry, geology, fluid-induced stress, sediment bearing strength, and oceanic environmental conditions.

Engineers work hand in hand with marine science and commerce; their interests span the range from theoretical to real applications. The demand (and salary) for such people is high and is expected to grow.

Physical Oceanography

The waters of the ocean move, as grand, persistent currents like the Gulf Stream, as large eddies that resemble atmospheric weather systems, as wind-generated surface waves that spread from ocean to ocean, as internal waves that carry momentum and energy without disturbing the surface, and as millimeter-scale motions that dissipate energy. The task of the physical oceanographer is to learn how this complex system of ocean motion functions.

Observational evidence is obtained by satellite; by shipboard instruments that yield a profile of the temperature, salinity, and depth of the ocean; and by moored instruments, such as the current meter, which can stay on a mooring for years storing measurements of currents and temperature.

Just 20 years ago, none of these instruments or systems existed in practical form. But together with electronic engineers and radio scientists, physical oceanographers have developed new instruments that now yield a mass of information from which exciting discoveries will come.

Ashore, theoreticians work with the complex equations that govern fluid motion on the surface of a rotating sphere. They construct computer simulation models of the motion and energy flow, and some turn to laboratory models for guidance. Most are drawn back to observational evidence to check their paper-and-pencil interpretations against the real ocean.

Because most of the thermal energy stored in the ocean-atmosphere system is held in the upper few hundred meters of the ocean, our weather depends on the processes by which this energy is exchanged with the atmosphere. An understanding of these processes is required to improve our predictions of climate and weather.

Ever-increasing development on shorelines and continental shelves calls for better knowledge of storms and the violent wave systems they produce. Growing pressure to use the oceans as disposal areas for all forms of human waste has created an urgent race to define the processes by which pollutants are spread.

Chemical Oceanography

Chemical oceanographers investigate the evolution of seawater and seafloor sediments to their present state, and the processes that contribute to their variability. They seek to understand the extent to which the environment may be changed, naturally or by man, and they study natural processes for clues to the origin of the oceanic crust. Rivers, sediment, the atmosphere, and volcanic rock affect the composition of seawater, and their influence is a matter of controversy for chemists considering the processes taking place at major ocean boundaries.

Over the last decade, marine organic chemistry has become one of the fastest-emerging fields in the environmental sciences. Both the chemical industry and government have become acutely aware of the need for chemists familiar with the environmental sciences. The work of these chemists includes determination of the amount of organic carbon produced in surface waters; the distribution, nature, and biogeochemistry of specific organic compounds in the marine environment; and studies of processes responsible for formation and diagenesis of organic matter in sediments. This is the essence of life on our planet.

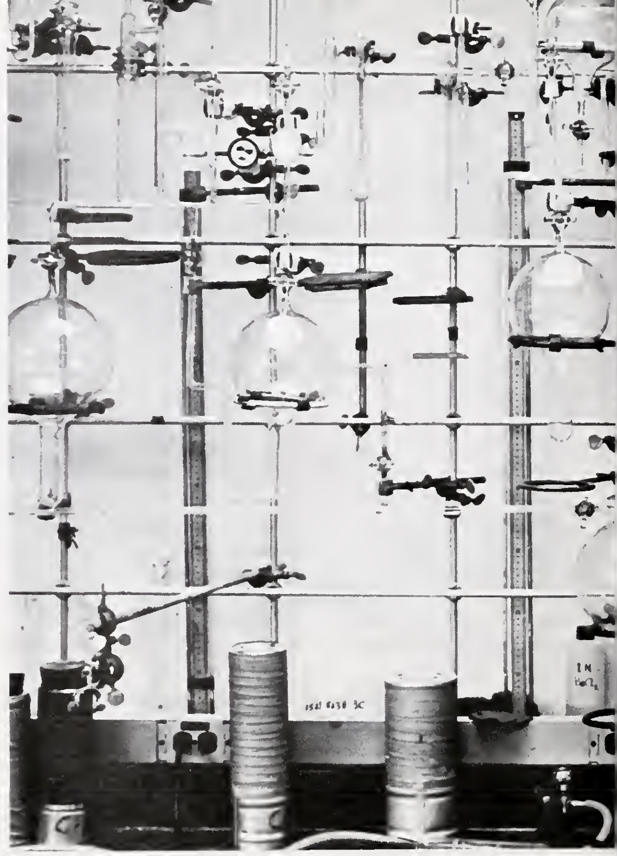
Biological Oceanography

Biological oceanographers seek to identify, quantify, and understand the dominant processes that determine the variety and abundance of life in the sea, as it changes from place to place and over time. Biological oceanography draws heavily on knowledge about aquatic organisms, on general ecological principles, and especially on the findings of chemical, geological, and physical oceanographers.

Most life in the oceans, like the interest of most biological oceanographers, is concentrated at the boundaries, the air/sea and sediment/water interfaces. Central issues include the factors that control primary production by phytoplankton, the pigmented, microscopic plants that inhabit the lighted zones of the ocean and fuel the biological

Marine geologists hand over a bag of rock samples collected with a submersible as part of a study of ancient reef formations. (Photo by J. L. Wray, University of Miami)

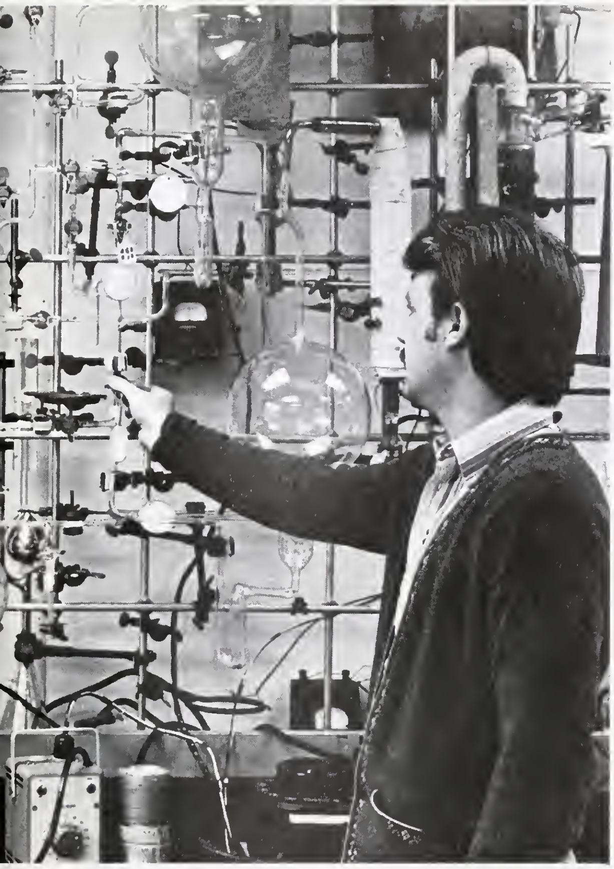
Biologist John Teal explains a sample to a graduate student aboard a Woods Hole Oceanographic Institution research vessel. (Photo by Vicky Cullen, WHOI)



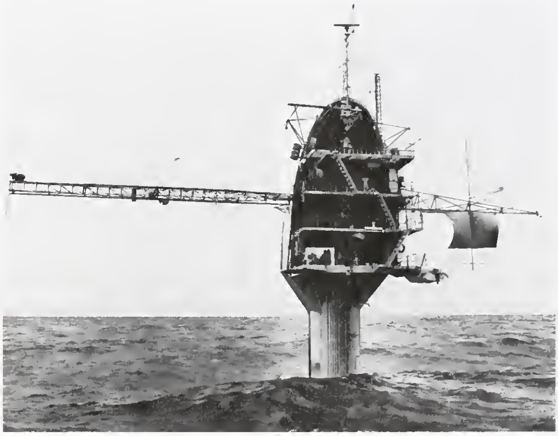
Part of the geochemistry laboratory at the Lamont–Doherty Geological Observatory in Palisades, New York. This equipment enables marine geochemists to determine the age of a sediment sample. (Photo courtesy of Lamont–Doherty Geological Observatory)

Members of a University of Florida coastal engineering crew struggle to set up a wind-measuring device on Perdido Key, Florida, just before Hurricane Frederick slammed ashore in 1979. (Photo by Mike Thomas)

Students relax in the sun on "Steel Beach." (Photo courtesy of Lamont–Doherty Geological Observatory)

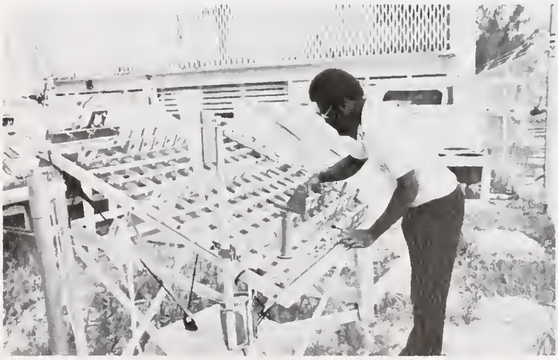


Sandy Shor, a graduate student, draws a contour map for his thesis on currents and sedimentation south of Iceland. (Photo by Alan Driscoll, WHOI)



FLIP, a 355-foot Floating Instrument Platform, was developed at Scripps Institution of Oceanography (SIO) in La Jolla, California. Towed to a research site, the assembly flips to the vertical position when its ballast tanks are flooded. Scientists and students then have a stable platform from which to study the sea. (Photo courtesy of SIO)

A United States Geological Survey technician operates an underwater drill in order to determine the geological history of an island. (Photo courtesy of University of Miami)



An ocean engineer on the campus of the University of Miami's Rosenstiel School of Marine and Atmospheric Science checks samples of various metal alloys for evidence of corrosion. (Photo by John Park, University of Miami) system. In what combinations and with what relative importance do the variables of nutrient availability, light limitation, physical mixing, and herbivory operate in various oceanic regimes? What determines the fraction of this production that works its way to herbivores and carnivores versus the fraction that fuels an active bacterial population or is lost from the system to fuel the bottom-living organisms below? Are the governing processes biological or physical?

Biological oceanographers are moving steadily away from case-by-case, species-by-species descriptions of life in the oceans. Foraging theory, adapted from theoretical ecology, is used to provide testable predictions about how various functional groups of organisms (bottom feeders, for example) ought to behave. The results of the ensuing experiments are then fruitfully generalized and can be incorporated into models of ecosystem behavior that apply to many species and trophic levels.

Chief areas of application for biological oceanography are in fisheries management and the management of waste disposal activities. Both endeavors rely on the continuing development of robust models of food-web transfer processes. The demand for biological oceanographers with an interest in organisms *per se* is not large. The new opportunities are largely for those holding special skills within the discipline and for those with sufficient breadth to communicate effectively with colleagues in sister disciplines.

Most growth in biological oceanography is going on either around new technology that allows old questions to be answered and new ones asked or around interdisciplinary questions that require the biological oceanographer's expertise. Examples of the former are rapid acoustic assessment of zooplankton patchiness, satellite remote sensing that allows synoptic views of medium- and large-scale spatial distributions of phytoplankton, and adaptation of cell-sorter and immunological techniques from the medical realm for rapid identification of phytoplankton and bacteria. Examples of the latter are the microbial role in marine mineral formation and in marine chemical transformations in general, the role of organisms in affecting the modes and rates of particle transport both within the sea and along the seafloor, and the role of organisms in determining the optical properties of seawater.

Visitors Welcome

Graduate education in all of these fields of oceanography is concentrated in a relatively small number of schools. All have openings for well-trained students. All welcome visitors, and a visit is the best way to learn about the important differences among schools. Anyone interested in a particular school should talk with a few professors and students there, to learn what they are like and how they spend their time, though it is important to make appointments with such people beforehand. Those unable to visit can ask questions in a letter or telephone call.

At present, most schools provide tuition aid for graduate work in oceanography, and students who are accepted are generally given some stipend for living expenses in the form of a research or teaching assistantship. The amount varies from school to school; typically it is enough to support (just!) a single person but not a family. More lucrative fellowships are awarded in certain fields for which the demand for graduates is strong, and these are growing in number. Such fellowships confer prestige on their recipients, who are allowed a great deal of freedom in choosing their faculty advisers and research topics — they are definitely worth applying for.

A student should apply to several schools, according to ambitions, field of interest, and academic record. Some schools offer more in some fields than others, but it is important to realize that centers of excellence can change as faculty members come and go. A visit is definitely recommended before finally accepting an offer from a particular school.

Students who are considering an oceanographic career but do not know enough about oceanography to make a definite commitment can obtain more information from the President of the Oceanography Section of the American Geophysical Union; 2000 Florida Avenue, N.W.; Washington, D.C. 20009.

Charles D. Hollister is Dean of the Woods Hole Oceanographic Institution. This article is a summary of contributions from more than 30 scientists and academic officers from the major universities and marine science research institutions of the United States and Canada.

Acknowledgments

The author would like to personally thank the following contributors, who represent virtually all of this country's oceanographic institutions:

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Bivalves As Sentinels of

How serious is chemical pollution of coastal areas? Where are the most polluted areas? Is chemical pollution increasing or decreasing? How rapidly? These questions were among those posed to scientists in the early 1970s by elected officials, government agencies, industry, and citizens groups. Just prior to and during that period of time, there had been several documented cases of severe chemical pollution in a few coastal areas (see *Oceanus*, Vol. 18, No. 1). Reasonable scientific extrapolation suggested that similar incidences might occur in other coastal areas if care were not exercised.

These extrapolations also suggested that many areas would not be severely polluted and areas with severe pollution would experience lower concentrations of chemical pollutants if the inputs of these chemicals were reduced. However, the issues were of such a serious nature that scientific extrapolations from a few measurements in a few locations at one or two points in time were unacceptable for assessments of what to regulate, where to regulate, and how long to wait for appreciable results in pollution abatement.

The U.S. Mussel Watch program has demonstrated that the bivalve sentinel organism concept can be a valuable tool for assessing the chemical pollution of the nation's coastal waters. Elevated concentrations of lead, polychlorinated biphenyls (PCBs), and fossil-fuel hydrocarbons have been documented for bivalves sampled in coastal waters near several major urban areas, in comparison to more remote, rural areas. In the case of releases from nuclear power plants, no systematic local or regional elevations were found in the several radionuclides monitored in bivalves from nearby coastal areas. Data-interpretation requirements have demonstrated the necessity of continuing interactions between environmental monitoring and environmental research.

Some Background

The United States Scientific Committee on Problems of the Environment (SCOPE) of the International Council of Scientific Unions (ICSU) convened an *ad hoc* meeting sponsored by the Environmental Studies Board of the U.S. National Academy of Sciences on March 31, 1975, to discuss strategies for monitoring marine pollution. Prior to that time, there had been various local and regional measurement strategies carried out in a few areas along the U.S. coast. The experience gained in these programs and elsewhere in the world, particularly Europe, Japan, and Australia, was evaluated at the meeting, which was chaired by Edward Goldberg of Scripps Institution of Oceanography. The consensus was to formulate and pursue a trial or prototype program of coastal chemical pollution monitoring on a national scale, using the sentinel organism concept. The common blue mussels, *Mytilus edulis* and *Mytilus californianus*, and oysters (*Crassostrea virginica*)

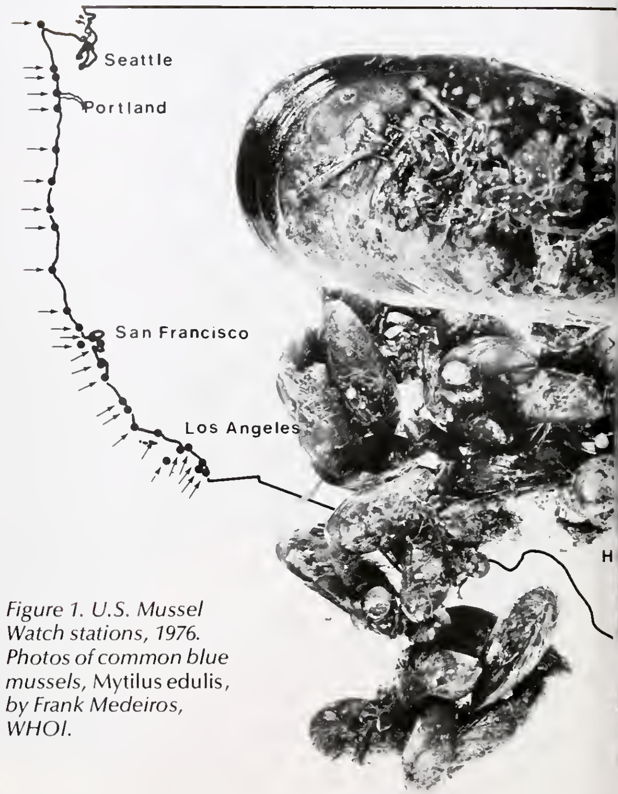


Figure 1. U.S. Mussel Watch stations, 1976. Photos of common blue mussels, Mytilus edulis, *by Frank Medeiros, WHOI.*

were chosen as the sentinel organisms. The reasons for choosing this strategy and these organisms were derived from hundreds of references in the literature of research and monitoring and can be summarized as follows:

1) Bivalves are cosmopolitan (widely distributed geographically). This characteristic minimizes the problems inherent in comparing data for markedly different species.
2) They are sedentary and are thus better than mobile species as integrators of chemical pollution in a given area.
3) They have reasonably high tolerances to many types of pollution, in comparison to fish and crustacea.
4) They concentrate many chemicals by factors of 10^2 to 10^5 compared to seawater in their habitat. This often makes trace constituent measurements easier to accomplish in their tissues than in seawater.
5) Inasmuch as the chemicals are measured in the bivalves, an assessment of biological availability of chemicals is obtained.
6) In comparison to fish and crustacea, bivalves exhibit low or undetectable activity of those enzyme systems which metabolize many xenobiotics such as aromatic hydrocarbons and polychlorinated biphenyls. Thus, a more

Coastal Chemical Pollution:

The Mussel (and Oyster) Watch

by John W. Farrington

EDITOR'S NOTE: Extensive excerpts from this article served as part of the testimony of the author May 26, 1983, before the House Subcommittee on Natural Resources, Agriculture Research, and Environment. The subcommittee of the full Committee on Science and Technology was investigating why, despite statutory requirements, Congressional oversight, and many existing monitoring programs, the United States does not have an adequate national environmental monitoring system.

accurate assessment of the magnitude of xenobiotic contamination in the habitat of the bivalves can be made.

7) They have many relatively stable, local populations that are extensive enough to be sampled repeatedly, providing data on short- and long-term temporal changes in the concentrations of pollutant chemicals.

8) They survive under conditions of pollution that often severely reduce or eliminate other species.

9) They can be successfully transplanted and maintained on subtidal moorings or on intertidal shore areas where populations normally do not grow — most often because of a lack of a suitable substrate — thereby allowing expansion of areas to be investigated.

10) They are commercially valuable seafood species on a worldwide basis. Therefore, measurement of chemical contamination is of interest for public health considerations.

The Mussel Watch Program: Implementation

A proposal, naming Professor Goldberg as Principal Investigator, was forwarded in mid-1975 to the U.S. Environmental Protection Agency (EPA) via Eric Schneider, then Director of the EPA Environmental Research Laboratory in Narragansett, Rhode Island. Funding was secured to begin sampling in 1976. This project was treated very much as a research project because 1) several of the measurements proposed for the program were in the early stages of analytical chemistry development and at that time could be accomplished in only a few laboratories, and 2) interpretation of the results required the close coupling of past and ongoing research in the participating investigators' laboratories.

The principal investigators involved in the project and the chemicals chosen for measurement are listed on page 20. Two laboratories were initially chosen for each type of chemical to be measured, in order to provide for redundancy in case a given laboratory ran into problems, to provide an interlaboratory check on data, to explore different approaches to new methodologies, and to reduce the burden of analyses for each laboratory. The choice of chemicals to be measured was based on the need to obtain data for representatives of several major classes of chemicals of environmental concern, for which analytical methodology was available or could be available after a few months of research. Chemicals of environmental concern are those that can or may have an adverse effect on marine biota in the coastal area or those that could represent a human health problem if accumulated to high concentrations in marine biota consumed by people.

The sampling locations for the first year of the program, 1976, are shown in Figure 1. Some changes in location were required in 1977 and 1978 because of changes in bivalve population densities, accessibility to collection sites, or the need to add stations because of special concerns regarding a given location.

The sampling locations were chosen by applying several criteria. We required stations near the major urban coastal areas; stations in remote, relatively pristine areas with low population density;

Mussel Watch Principal Investigators

Dr. Edward D. Goldberg, *Scripps Institution of Oceanography, Geological Research Division, La Jolla, California* — Principal Investigator of the project. radionuclide analyses (plutonium 239, 240) and trace metal analyses (copper, zinc, nickel, silver, lead, cadmium).

Dr. Vaughan T. Bowen, *Woods Hole Oceanographic Institution, Woods Hole, Massachusetts* — radionuclide analyses (plutonium 239, 240).

Dr. John W. Farrington, *Woods Hole Oceanographic Institution, Woods Hole, Massachusetts* — halogenated hydrocarbon (PCB and DDT)[1] and hydrocarbon analyses.

Dr. Robert W. Risebrough, *Bodega Marine Laboratory, University of California, Bodega, California* — halogenated hydrocarbon (PCB and DDT) and hydrocarbon analyses.

Dr. John H. Martin, *Moss Landing Marine Laboratory, Moss Landing, California* — trace metal analyses (as above).

Dr. Patrick L. Parker, *Marine Station, University of Texas, Port Aransas, Texas*— hydrocarbon analyses.

Dr. John Laseter, *Center For Bio-organic Studies, University of New Orleans, New Orleans, Louisiana* — participant in the intercalibration exercise.

Mr. Walter Galloway, Drs. Donald K. Phelps, James Lake, Peter Rogerson, *U.S. EPA Environmental Research Laboratory, Narragansett, Rhode Island* — coordinators of intercalibration exercises, 1979-1980.

[1]Dr. George R. Harvey, now at the Atlantic Oceanographic and Meteorological Laboratory, NOAA, Miami, Florida, was a Principal Investigator during 1976.

and stations along the coast that were neither obviously urban nor pristine. Mussel or oyster populations had to be large enough to sustain repeated sampling over the years. Each sampling required more than 400 individual bivalves for the various analyses. With only a few exceptions, access had to be relatively easy, because of budget restraints of $400,000 for the first year and the same amount for the next two years. Bivalve populations had to be stable and have a history or promise of maintaining themselves over a period of several years to provide a time course of measurements for a given location. Several stations were chosen because they were near nuclear power plants or near river mouths or estuaries with nuclear power plants sited upriver. We sought and received valuable advice on station selection from colleagues at federal, state, and private marine laboratories and oceanographic research centers around the United States. Many more stations were proposed than could be accommodated within our funding restrictions.

Stations finally chosen were on the outer coast, at the mouths of estuaries, or in a few selected harbors. The sampling was designed to support an assessment of regional or temporal trends in chemical pollution along the outer coast of the United States. Since several estuaries, such as Chesapeake Bay and Narragansett Bay, were the sites of ongoing research programs for the cycles of several chemical pollutants, estuaries were not extensively sampled, even though we recognized that pollution often increases in severity along transects from the mouths to the heads of estuaries near urban areas.

Each year, a team of two collectors traversed the entire coast of the United States collecting samples. This collection by a single group, supplemented by a few local collections by the principal investigators, ensured uniformity of collection and site-description procedures and also ensured that samples were not compromised during the collection and shipping process. The samples were stored in a freezer in a trailer and periodically were shipped frozen to the laboratories for analysis. In a few cases, the locations of suitable oyster reefs were kept secret by commercial fishermen, and we had to purchase samples from them.

Two locations were chosen to measure seasonal and monthly fluctuations in concentrations of chemicals. We knew from published data that body burdens of chemicals could be influenced by spawning activity and changes in metabolism related to fluctuations in habitat temperature. Thus, we needed these special data sets to constrain and interpret the larger national data set, for which samples only could be collected yearly, initially, because of funding constraints. The sampling sites chosen for the monthly samples were Bodega Head, California (*Mytilus californianus*), a remote, relatively pristine site; and upper Narragansett Bay, Rhode Island (*Mytilus edulis*), at a moderately polluted site. These data will not be discussed here, but we have used them to interpret the national data sets for this program.

The analytical chemistry methodology is also beyond the scope of this article. However, it is important to note that the measurements are trace constituent measurements. Concentrations of the chemicals measured are in the parts-per-million* to parts-per-billion** range or even less. We are often asked: "Why measure concentrations at such low levels that they might have few, if any, adverse effects on marine biota and are well below U.S. Food and Drug Administration (FDA) action levels for restricting human consumption?" The answer is in three parts. *First,* we should be capable of detecting increasing coastal environmental burdens of real and potential chemical pollutants well before they reach levels having an adverse impact or before they become a threat to seafood consumers. This early warning will allow for more calmly considered

*One part per million is 10^{-6}, or one-millionth, of a gram of a chemical per gram of tissue. **One part per billion is 10^{-9}, or one-billionth, of a gram of a chemical per gram of tissue. In understanding the significance such tiny quantities of chemicals can have, consider that one or two tablets of aspirin contain between 250 and 500 milligrams, or thousandths of a gram, of aspirin. If evenly distributed throughout the body of a 150-pound (68 kilogram) person, this would amount to about 4 to 7 parts per million of aspirin.

Some Sources of Coastal Pollution


a


b


c

d


e


f


g


h

Lead and polycyclic aromatic hydrocarbons enter coastal waters from the atmosphere when fossil fuels are burned (a, b, c) and from storm sewers (d) and other outlets for urban runoff and industrial effluents. Some oil may leak or spill from refineries (e) and tankers (f). One use of polychlorinated biphenyls (PCBs) was in electrical capacitors, some of which were disposed of in landfills (g). Seawater contains plutonium from the fallout after nuclear weapons tests (h). (Photos courtesy of UNESCO, Friends of the Earth, Massachusetts Port Authority, U.S. Fish and Wildlife Service, American Petroleum Institute, John Sheckler/New Bedford Standard-Times, *and the* Bulletin of the Atomic Scientists*)* remedial action and protection strategies compared to the many costly, rear-guard, firefighting-type remedial activities of the past decade, typified by present Superfund hazardous waste programs. *Second,* we will be able to detect the response of the coastal environment to the reduced inputs of chemicals such as polychlorinated biphenyls, for which production has ceased in the United States; or lead, since regulatory action decreased the amount of tetraethyl lead in gasoline. *Third,* we are learning important lessons from present distributions and cycling of chemical contaminants that will assist us in predicting the behavior of man-made chemicals that might be released to the environment in the future. This forms part of the knowledge that is used along with toxicity studies to determine if a particular chemical should be released to the environment and, if so, how much and in what manner.

Results and Interpretations

The facets of the results and interpretations of the first three years of the program are too numerous to mention in detail here, but a brief synopsis of a few examples of data and interpretations will be presented.

Polychlorinated Biphenyls

These chemicals are produced by chlorination of the biphenyl molecule, which theoretically can produce mixtures of up to 200 individual chemicals. Most commercial mixtures contain a more limited array of 50 to 100 individual chlorinated biphenyls. The mixtures of PCBs have many uses because they have high stability, low water solubility, low volatility, and a high dielectric constant, and are nonflammable. PCBs have been used in open systems in hydraulic fluids, heat transfer fluids, lubricating and cutting oils, paints (including boat paints), inks, sealants, and resin extenders. PCBs have been used extensively in closed systems as dielectrics in transformers and large capacitors in electrical systems. The main point is that PCBs had and have pervasive use throughout industrial societies, such as the United States.

Environmental and human health problems with PCBs were responsible for the cessation of open-systems use of PCBs around 1972 and the cessation of production in the United States in 1977. Despite these actions, much of the PCBs produced was still in use or in various disposal and landfill areas at the time of a study by the National Academy of Sciences, published in 1979. The situation has probably changed very little since then, although some effective cleanup programs are now in progress for large closed systems and for some of the contaminated disposal sites.

Figure 2 provides data for the West Coast samples of the Mussel Watch program. There is no significant difference in the data from 1976 to 1977 to 1978. The differences between concentrations at a given station from one year to the next are within the expected differences noted for analytical

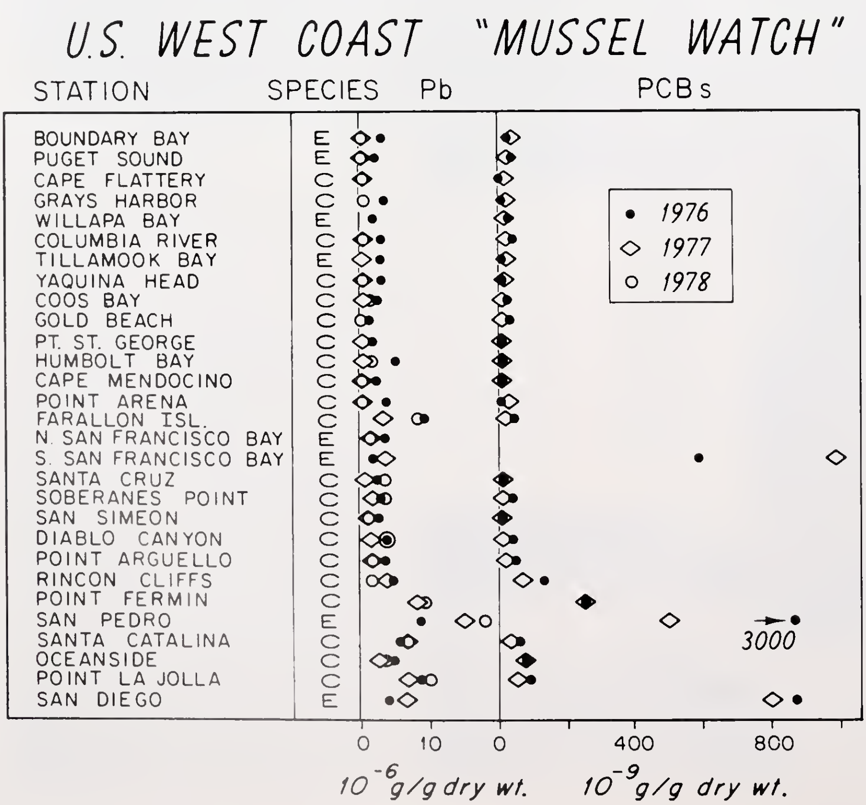


Figure 2. Concentrations of PCBs (polychlorinated biphenyls) and Pb (lead) in mussels from the West Coast sampling sites. C refers to the Mytilus californianus species. E refers to the Mytilus edulis species. (From Farrington and others, 1983)

measurements and expected temporal variability based on the Narragansett Bay and Bodega Head data sets.

Given the types of uses previously discussed and disposal practices of the 1950s to 1980s, we would expect some areas of elevated PCB concentrations near urban centers. Indeed, that is what we find on the West Coast, with elevated PCB concentrations near San Diego, San Pedro (Los Angeles), and San Francisco. Concentrations are much lower in samples from the more pristine, less populated areas of the northern California, Oregon, and Washington coasts. These findings are the same for the East Coast (Figure 3), where we find that there is a "Northeast Megapolis Effect" of elevated PCB concentrations associated with the highly populated and industrialized northeast coast.

The data also show a sample in 1978 for the Acushnet River Estuary–New Bedford Harbor area mussels (Figure 3), clearly identifying this area as a "hot spot" of PCB pollution. A follow-up to these and other measurements by a combination of federal, state, and academic laboratories has clearly shown this site to be heavily polluted with PCBs as a result of releases to the harbor area by two electrical component manufacturing companies. In 1982, this area was designated a Hazardous Waste Superfund Site by the EPA. A Remedial Action Master Plan for PCB pollution abatement in the area is now in the final stages of formulation.

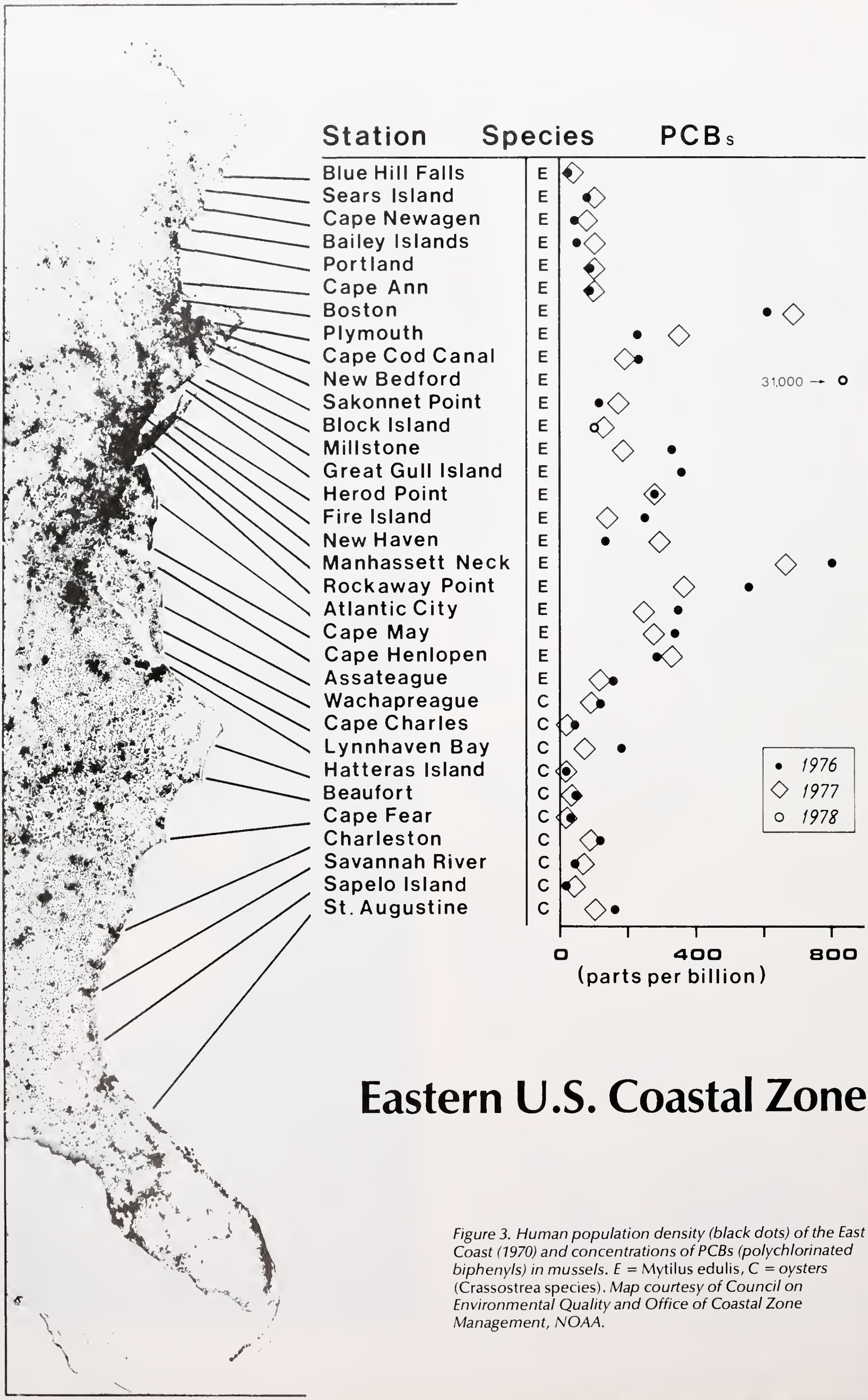
We found that the plot of data such as that shown in Figure 3 was compelling, and we convinced several local and state elected and appointed officials that this site was severely contaminated in comparison to several other areas on the United States coast and deserved further immediate attention. This is one value of a regional and national data set. It provides one means of comparison for identifying areas of special concern.

Only the Acushnet River Estuary–New Bedford Harbor mussels contained PCB concentrations close to or in excess of the 5 ppm *wet weight** concentration set by the FDA as a recommended upper limit for seafood for human consumption. It is sobering to note that the cessation of open use and the ban on production of PCBs were implemented none too soon for the protection of a sizable area of the northeastern U.S. coast and other urban areas on the coast from PCB concentrations in bivalves in excess of the FDA limit. Our data is not as complete for the coast along the Gulf of Mexico as it is for the east and west coasts, but the analyses to date in the Gulf coast area are consistent with general conclusions from the other coasts.

Lead

Lead data for the West Coast are presented in Figure 2. Lead concentrations are elevated near the southern California urban areas of San Pedro Harbor (Los Angeles) and San Diego. The high lead concentrations near these areas have been linked with atmospheric inputs and sewage, storm, river, and coastal runoff contributing lead from the

*An average wet-weight-to-dry-weight ratio is 8 to 1.



Eastern U.S. Coastal Zone

Figure 3. Human population density (black dots) of the East Coast (1970) and concentrations of PCBs (polychlorinated biphenyls) in mussels. E = Mytilus edulis*, C = oysters (*Crassostrea *species). Map courtesy of Council on Environmental Quality and Office of Coastal Zone Management, NOAA.*

combustion of lead compounds in gasoline. Elevated values for lead also were noted in a few samples from around the New York and Boston areas. However, oysters sampled near urban areas of the southeast and Gulf coasts did not have elevated concentrations compared to those sampled near less populated areas. The reasons for this difference are unknown at this time. Lead, unlike PCBs, has a natural source in the environment, and anthropogenic discharges are adding to a natural background of lead. The value of systematic measurements of lead in bivalves from a variety of types of coastal areas is to provide a relative assessment of natural versus man-mobilized lead burdens in coastal biota.

Fossil-Fuel Hydrocarbons

There are a variety of sources of input of fossil-fuel hydrocarbons to coastal areas (see *Oceanus*, Vol. 20, No. 4). These range from oil spills to chronic dribbling of oil via sewage, urban runoff, industrial effluents, and combustion of coal, oil, and gasoline. Polycyclic aromatic hydrocarbons (PAH) are part of the fossil fuel compound assemblage, and several of the PAHs are of concern because they can have adverse impacts on biota, depending on concentrations, duration of exposure, and the particular species in question. Other PAHs are known or suspected mutagens and carcinogens. Thus, the route back to man from various inputs and the current status of PAH concentrations in marine biota are important for public health considerations. In brief, the Mussel Watch data showed elevated concentrations of fossil-fuel compounds near urban areas in comparison with remote rural areas. This was expected, although the exact details of distributions were not known; the measurements provided the needed confirmation.

There was a surprise in some of this hydrocarbon data. Previous measurements of polynuclear aromatic hydrocarbons had been made in sediment samples from several U.S. coastal areas — particularly the northeastern United States. Polynuclear aromatic hydrocarbons are present in crude oils, fuel oils, and in particulates released during combustion of coal, oil, and gasoline. There are distinct differences in chemical composition between the PAHs that originate from combustion and those derived from crude oil or fuel oil. The combustion-source PAHs predominate in sediments near urban areas, where elevated concentrations are found. These PAHs also are present, at much lower concentrations, in sediments in remote areas. However, the mussels with elevated polycyclic aromatic hydrocarbon (PAH) concentrations near urban areas had a mixture of PAH with a composition indicative of either a mixture of combustion-source PAH and petroleum PAH or, more often, a predominance of PAH from petroleum sources — crude oil or fuel oil spills or chronic petroleum release in effluents and urban runoff.

We do not have a complete explanation for this as yet. However, the working hypothesis we are currently testing is as follows. The petroleum compounds are probably more available for uptake by bivalves than the compounds from combustion sources. We think this is a result of the stronger

Researcher at the Woods Hole Oceanographic Institution prepares mussels for analysis. (Photo by Vicky Cullen, WHOI)

binding of the combustion-source PAHs to particles released from combustion sources. Chemical extractions used for sediment analyses would remove these PAHs from the particles. Mussels and oysters probably ingest combustion-source PAH particulates during feeding but pass them through their digestive systems with minimal uptake. In comparison, petroleum-source PAHs are present in the habitat of bivalves in dissolved or dispersed form in the water, not tightly bound to particulate matter. These petroleum-source PAHs would be more readily available for uptake from water across gill surfaces or during feeding on particulate matter.

Thus, sediments primarily record the overall geochemical cycle of PAHs in the coastal environment, while the bivalves provide a better assessment of that portion of the PAHs available for uptake by biota. We do not propose absolutes. Some of the combustion-source PAHs are taken up, and a small portion of the petroleum PAHs are probably not available for uptake. Further studies to confirm or modify this hypothesis are in progress.

There are important implications in this for pollution abatement policies. Until recently, it was thought that one of the more significant sources of PAH input to the coastal environment was combustion of fossil fuels. PAH inputs from other sources were thought by some to be quantitatively less important. In considerations of pollution abatement in coastal areas, greater attention is given to combustion sources in order to reduce the potential for long-term adverse effects. The hypotheses we have set forward, using the combined interpretation of "Mussel Watch" and sediment analyses data, suggest that we should focus more or equal attention on reducing petroleum PAH inputs. At the very least, we need to study this situation, which is easily amenable to experimental testing of our hypothesis.

Comparison of Data

Concentrations of PCBs, lead, and fossil-fuel hydrocarbons are elevated in bivalves near most large urban areas we have studied. Despite this general coincidence, there is not a strict one-to-one correlation of elevated concentrations for these chemicals because the mechanisms of release to the environment are different. There are natural background levels for lead and fossil-fuel hydrocarbons, and the biogeochemistries of these chemicals are sufficiently different that they sometimes move through coastal environments at different rates.

In the United States, both lead and PCBs are subject to regulations that are intended to reduce and restrict the anthropogenic inputs to the environment. There is no evidence in our data of reductions in lead or PCB concentrations between 1976 and 1978, a period of time during which regulatory actions for lead and PCBs were implemented. This results from the fact that anthropogenic inputs from previous years were and still are in the coastal biogeochemical cycles, particularly in the sediments of urban harbors and estuaries. It may be another five years or more before definite indications of large-scale reductions of lead and PCB concentrations, compared to the 1976 data, will occur in coastal regions. However, the existence of the 1976-to-1978 data will allow us to assess the rate and extent of reduction in response to regulatory action.

Plutonium

Plutonium isotopes are man-made radioactive chemicals that enter the environment during nuclear weapons testing or from leaks during the nuclear fuel cycle. Measurements are conventionally expressed as dpm (disintegrations per minute), which are a function of radioactive decay and are proportional to the amounts of plutonium present. Data for two of the most common plutonium isotopes, combined in the Mussel Watch analysis techniques, are presented in Figure 4 for West Coast samples. There are elevated concentrations in the central California coastal areas, although the concentrations are very much lower than those that would be of immediate concern from a public health perspective. The geographic coincidence of elevated plutonium concentrations in the general location of the radioactive waste canisters dumped to the seafloor off the Farallon Islands (see *Oceanus*, Vol. 25, No. 4) caused some who had access to the unpublished Mussel Watch data to prematurely conclude that plutonium released from the disposal site was reaching surface waters. That conclusion was incorrect.

Data from long-term, ongoing research programs had clearly shown that plutonium fallout from nuclear weapons testing in the 1960s was present in higher concentrations in mid-depth North Pacific water (approximately 500 to 1,000 meters) compared to lower concentrations in surface waters and deeper waters. Research off the coast of California by several scientists, including John Martin, who was a principal investigator in the

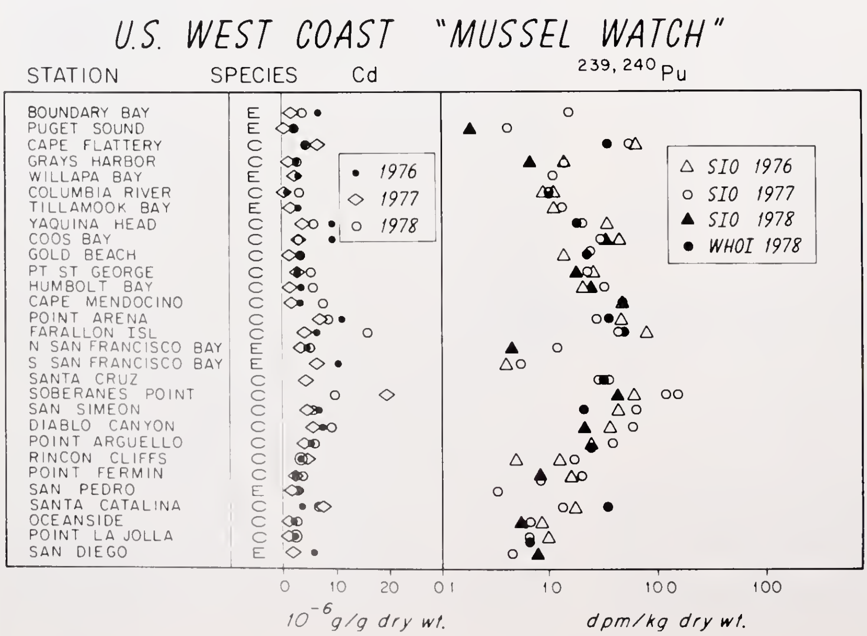


Figure 4. Concentrations of cadmium (Cd) and isotopes of the man-made radionuclide plutonium (Pu) in West Coast samples. (From Farrington and others, 1983)

Mussel Watch program, had shown that cadmium (Cd) was actively mobilized during cycles of upwelling in coastal waters. Elevated Cd concentrations in some of the mussel samples in the region are attributed to more intense upwelling off the central California coast compared to areas to the north or south (Figure 4). The best evidence available shows that upwelled mid-depth North Pacific water is supplying elevated plutonium concentrations to the central California coastal surface waters, and the mussels there are reflecting this increase in concentration.

Concentrations of plutonium for the entire East Coast mussel and oyster collections were similar to the concentrations for the Oregon, Washington, and southern California coasts. None of the man-made radionuclide data for the Mussel Watch samples showed evidence of local or regional systematic elevations of environmental concentrations as a result of effluent releases from nuclear power reactors. The data are all consistent with what we know about the biogeochemical cycles of worldwide fallout from nuclear weapons testing.

Two important points are illustrated by the plutonium data and interpretation. First, national and regional surveys on a systematic basis were needed to clearly identify elevated concentrations of plutonium in mussels of the central California coast. Second, a close coupling of oceanic research with these prototypical monitoring measurements was essential to correct interpretation of the data.

A further illustration of the importance of having these systematic surveys is a consideration of the "what-if" scenarios surrounding the Three Mile Island nuclear power plant incident. The Mussel Watch program had been in progress, and collections of samples and initial data for the East Coast were already available prior to that incident. If there had been substantial release of radioactive chemicals with a concomitant concern about transport through the environment and along the coast, then the Mussel Watch collections and data could have provided a sensitive bench mark for survey of any releases from Three Mile Island.

Continuing Activities and a Perspective

Further limited collections and analyses of samples from the California and northeastern U.S. coasts and monthly collections from Narragansett Bay, Rhode Island; Bodega Head, California; and Beaufort, North Carolina, have been completed since 1978 or are in the final stages. A considerable amount of research has focused on refining the relationship between concentrations of chemicals in mussels and concentrations in the water and sediment of their habitat.

There also has been an emphasis on two aspects of analytical chemistry methods: intercalibration of measurements between laboratories and identification and more accurate quantitative measurements of the myriad anthropogenic petrochemical compounds and pesticides released to the environment and present in shellfish samples.

The intercalibration efforts are required to provide a framework within which data for the same chemicals but from different laboratories can be compared and interpreted. Many of the methods of measuring low concentrations of chemical pollutants are new, and it is essential that these methods be checked very carefully. The details of these exercises would be dull reading for most people. However, these measurements are very difficult and demanding, and require constant checks to ensure high-quality data. There are national and international intercalibration exercises. Our laboratory is presently preparing subsamples of a puree of tissues from more than 4,000 mussels for distribution to laboratories of our colleagues here and in other countries, as part of a joint ICES (International Council for the Exploration of the Seas)–IOC (International Oceanographic Commission of UNESCO) intercomparison exercise. This is part of a continuing series of exercises that are bringing us to the point where we will be able to compare our data with those from other countries, to provide a wider global perspective on chemical contamination in coastal waters.

PCBs, DDT, and polycyclic aromatic hydrocarbons are only a few of the thousands of petrochemicals produced over the years. A large number of trace impurities and side-reaction products also result from the manufacturing process. Many of these chemicals leak or are deliberately discharged to the environment. Once these compounds are released, a complicated series of reactions can possibly transform them into other compounds.

Fortunately, the incidences where the initially released compounds or their reaction products are of concern because of their adverse impacts on biota and, more specifically, their threat to the health of man, are relatively few. Despite the greater attention to environmental concerns and an increase in the knowledge of the fate and effects of pollutants in the environment, we must guard against the surprises that cropped up during the last two decades.

The signals from our analytical instruments, such as the gas chromatograph–mass spectrometer systems, record the presence of hundreds of chemicals of unknown identity in the mussel and oyster samples. Many of the chemicals are of natural origin, but many others are only present or primarily present in samples taken near urban industrial areas. Are a few of these new compounds of future environmental concern? Research is in progress to minimize the chance of society being taken by surprise by the buildup of an unrecognized environmental pollutant. Modifications of computerized identification and data systems are being pursued to enhance analyses and the filing, retrieving, and display of data, in order to keep track of more of the petrochemicals released to the environment and recorded in bivalve tissue.

Another important segment of the Mussel Watch program has been the maintenance of a frozen set of archive samples from the national collection sites for 1976 to 1978. There is no doubt that analytical methods of measurement are improving at a rapid rate and new instruments with greater selectivity and sensitivity are being developed. The archived samples allow the

Mussel Watch station on Bailey Island, Maine. (Photo by Hovey Clifford, WHOI) possibility of retrospective analyses of collections from 1976, 1977, and 1978. When new compounds of concern are identified, and a time-course of the buildup of coastal-ecosystem burdens by these compounds is desired, the archived samples can be analyzed.

Bivalve sentinel organism programs have been in progress in other countries — for example, Britain, the Netherlands, France, Spain, Australia, and Japan — over the same time period and, in some cases, earlier than in the United States. Researchers from many countries met in December of 1978 in Barcelona, Spain, under the auspices of the Environmental Studies Board of the U.S. National Academy of Sciences and under contract from the EPA, to exchange ideas and evaluate the state of the art at that time. A similar meeting is scheduled for November of this year at the East-West Center, in Hawaii. It will be sponsored by SCOPE and by IFIAS (International Federation of Institutes for Advanced Studies). The United Nations, through organizations such as IOC-UNESCO and the UN Environment Program, is evaluating the use of sentinel organism analyses in pilot programs for assessing environmental quality in coastal areas.

The concept of chemical sentinel organism programs has been extended into the biological effects arena. The combination of chemical and biological measurements provides powerful tools for assessing the status of environmental quality in coastal waters. The national Mussel Watch activities have been coordinated during the last several years with the Coastal Environmental Assessment Stations (CEAS) program of the EPA's Environmental Research Laboratory in Narragansett, Rhode Island. The CEAS program, under the leadership of Donald K. Phelps of EPA, has been investigating the use of mussels transplanted in cages hung on moorings along a gradient of chemical pollution in Narragansett Bay. The caged mussels are analyzed for trace metals, PCBs, and petroleum hydrocarbons in the same manner as the national Mussel Watch collection. In addition, Phelps and his co-workers have made physiological measurements of the health of these mussels, using techniques developed over the last several years by a wide range of marine biologists — notably Brian Bayne of the Institute of Marine Environmental Research in Plymouth, England. There are several other activities of a similar nature, completed or in progress, where the sentinel organism concept is being used in research and monitoring activities.

The Future Challenges

The renewed concern with waste disposal in the ocean (see *Oceanus*, Vol. 24, No. 1) has focused attention once again on coastal environmental quality issues. The sentinel organism, or Mussel Watch, concept can assist in assessing the present status of chemical pollution in U.S. coastal waters by identifying areas of the coast that require special attention and providing a long-term monitoring capability. However, the Mussel Watch concept must not be viewed as a panacea for understanding all important aspects of the biogeochemistry of pollutant chemicals in coastal areas. The Mussel Watch program was a prototype for one approach to monitoring for chemical pollutants. It yielded data that was usefully interpretable within the context of the present knowledge of biogeochemical processes that we have gained from research. This latter point is a crucial consideration for future monitoring efforts. The close coupling between research and monitoring was very important to the interpretation of data, as was illustrated by the discussion of the plutonium data and the polycyclic aromatic hydrocarbon data.

The challenge for the future is to transfer the prototype to an operational monitoring program while still maintaining close collaboration with researchers. This requires careful consideration of the operational needs of a monitoring program, and of how best to integrate this program with other research and monitoring efforts aimed at understanding the input, fates, and effects of pollutants in coastal ecosystems. In particular, we are increasing our capabilities to measure chemicals of environmental concern. These capabilities must be matched by increasing our understanding of what a given concentration of a chemical or mixtures of chemicals means in terms of the health of an ecosystem and the health of consumers of seafood.

An important part of the continuing challenge, and a part that has been difficult over the last three years, is to interface scientific knowledge, capabilities of research, and monitoring, to the policy and management issues of marine environmental quality. One part of an ongoing, multi-institutional, international project of the International Federation of Institutes for Advanced Study, called Analyzing Biospheric Change, addresses this challenge.

John W. Farrington is Director of the Coastal Research Center at the Woods Hole Oceanographic Institution and a Senior Scientist in the Chemistry Department.

Acknowledgment
The author wishes to extend his appreciation to the other scientists involved in the Mussel Watch project for the many personally and scientifically enriching experiences he has had during participation in the project. Many dedicated associates in the laboratories of the principal investigators have worked diligently over the years since 1976, shucking, weighing, and analyzing thousands of mussels and oysters, while providing high-quality data week after week. Their efforts are very much appreciated.

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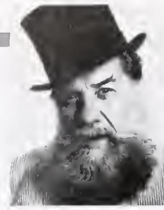
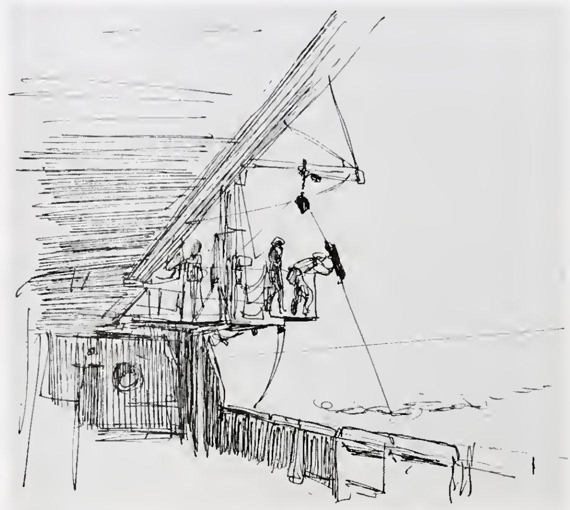


An Artist Goes to Sea, Reviving an Old Tradition

Crossing the equator on board the Beagle, *by Augustus Earle. Traditionally, those making their first crossing at sea must be initiated; as Darwin wrote to his family: "This most disagreeable operation consists in having your face rubbed with paint and tar, which forms a lather for a saw which represents the razor, and then being half drowned in a sail filled with sea-water." (From* Charles Darwin and the Voyage of the Beagle, *Nora Barlow, ed. 1945. Courtesy of George Rainbird, Limited.)*



Seen from the stern of Oceanus, *scientists bring in a water sample, while trying to cope with a wire angle that is not the best. The Niskin bottle weighs about 20 pounds and, once unhooked from the wire, must be brought on board with sheer muscle-power.*

Before photography was popularized, visual recordings had to be made by human hands. Expeditions to faraway parts of the globe, from before Magellan's time to the early days of scientific research, carried draftsmen to draw pictures of points of interest. Sometimes the captain or one of the mates did the sketching, but frequently the ship's artist had no duties other than drawing. On reaching a potential landmark, such as an inlet or high bluff, the draftsman began work. Noting the ship's position, he drew the landmark. In this way, should the ship return to the same spot, the captain could be sure of his location. As well, the drawings might be used for study back home, or for reference by future navigators in the area.

After European explorers had visited most parts of the world, artists were still needed on some expeditions. One well-known voyage is that of the HMS Beagle, *on which young Charles Darwin sailed (from Devonport, England, 27 December 1831) around the world. Though Darwin is now the most celebrated veteran of that trip, at the time he was simply a naturalist, brought along at the behest of the captain, Robert FitzRoy. Another important member of the* Beagle's *crew was the artist, Augustus Earle. When Earle's health failed and he had to leave the expedition, he was succeeded by Conrad Martens, whom FitzRoy met and engaged at Montevideo (now the capital of Uruguay).*

The Beagle *returned to England in 1836; in 1872 the H.M.S.* Challenger *set out, "to examine the physical and biological conditions of the deep sea throughout the great ocean basins." Though other ships had made*

Drawings by
Sigmund Purwin

***An officer and a crew member standing watch on the bridge of the* Oceanus.**

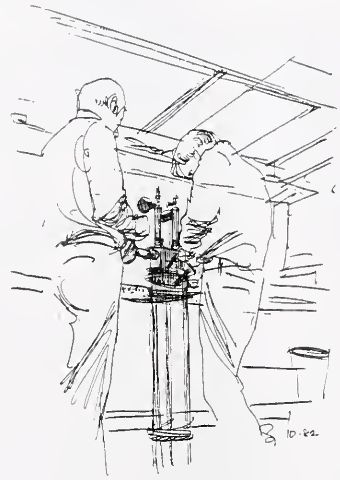
scientific forays, the Challenger's *trip marks the birth of modern oceanography. On board was Dr. J. J. Wild, who served as artist to the expedition and private secretary to the director of the civilian scientific staff. Wild produced many drawings of scenery and animals, which were later made into woodcuts and engravings.*

By the time the Challenger *returned, in 1876, photographs were beginning to share space with woodcuts in official reports. Since then, photography has proliferated, and, on board ships, drawing has all but died out.*

However, there are people interested in what life at sea is like, and those who would record it with pen and paper. One such person is Sigmund Purwin, a freelance artist living in Falmouth, Massachusetts. Last summer, Purwin was able to go aboard the research vessel Oceanus *(one of the Woods Hole Oceanographic Institution's ships) for Cruise 126, a 12-day venture. Thus the* Oceanus, *with a scientific party of 10 and crew of 12 (including the captain) sailed with the company of one artist. They were bound for the Grand Banks, off Newfoundland, where they would study certain microbial populations and processes.*

To get to the Grand Banks, the Oceanus *would steam for 3½ days. That time would not be wasted, however. Setting up the laboratory was the first order of business: scientific work would commence immediately upon reaching the first research station. Once there, the scientists planned to take cores of the sediment to look for products of microbial metabolism, and to study the rates of microbial activities, using a special canister to incubate samples* in situ. *They also planned to collect*

(a)



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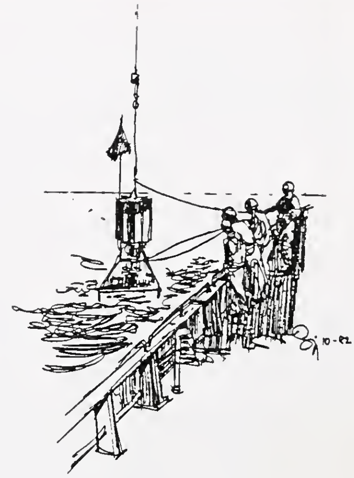

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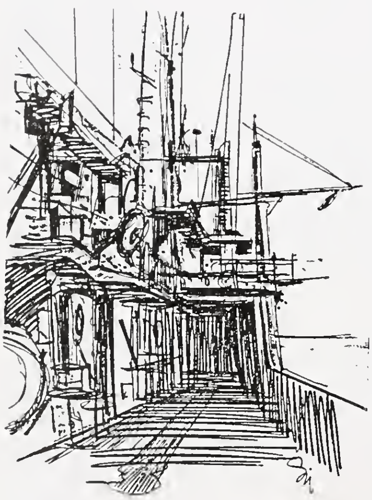

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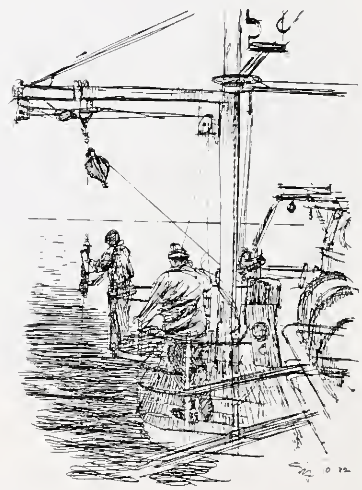


(f)

many water samples, in order to study the distributions of different kinds of luminescent bacteria in the water column.

Later in the cruise, the Oceanus *would steam eastward into deeper waters. Water samples would be collected from 3,600 meters down and kept in heavy titanium cylinders at their* in situ *pressure, to study the effects of pressure on deep-sea bacteria.*

By the evening of the second day out, preparations were complete. After dinner, a special feature was announced: an art class. Purwin demonstrated "roller art" — one of his specialties — using a small brayer (roller), acrylic paint, and paper. Then everyone got a try, and shortly many colorful paintings hung on the laboratory walls.

When the official mission of the cruise got started, Purwin did, too. He roamed the decks with his pad of paper, drawing mostly with pencil and an assortment of black felt-tipped pens. He peeped into the lab from time to time, keeping an eye on the doings there. He says he didn't want to ask too many questions, but that turned out not to be a problem: "They wanted *to explain their equipment to me, this yo-yo coming on board."*

Purwin is interested in engines and machinery, and made some sketches of the ship's innards. Most of his pictures are of people, at work and at leisure. It did not take long for those on board to get used to Purwin's presence, and to lose whatever self-consciousness they may have had to begin with. Viewing the sketches months later, one person commented, "I didn't even know he was there."

(a) Page opposite: Bringing up a gravity core — this job requires three hands because of the 300-pound lead weight the corer carries. (b) Scientists transferring water samples, brought up from 3,600 meters, from a pressurized water sampler to smaller containers. (c) Scientists and crew members retrieving a tripod that incubates sediment samples *in situ*. After digging into the seafloor, the tripod injects each sample with a radioactive substrate; later, scientists can measure the rate at which bacteria metabolize the substrate. (d) The view forward on the starboard side. (e) Scientist taking out sediment sample from gravity corer. (f) Looking abaft, a scientist, with the winchman's help prepares to cast Niskin water bottles off the hydro platform on *Oceanus'* starboard side.

Paintings made with luminescent bacteria, photographed in the dark.

One of the scientists introduced Purwin to a new painting technique: drawing on agar (special gelatin for bacteria to grow on) with luminescent bacteria. To do this, one dips a wand-like utensil into a growing culture, then trails it along on a fresh agar-plate, wherever a line or colored-in place is desired. The bacteria require one day to grow. To see the glowing pictures, the lights must be turned off.

While sailing with the Oceanus, *Purwin daily jotted in a journal. On the ninth day out, he noted that "art awareness" was catching on. The steward decorated one man's breakfast omelette with cheese slices cut out to be a ship and waves.*

The cruise ended in St. John's, Newfoundland. Another scientific party would join the Oceanus *there; for this group, it was time to pack up the lab, the samples, and the paintings, and go home — via airplane.*

For Purwin, it was the end of his first voyage on a research vessel. Why did he want to do it? He is not really sure. Since that trip, though, Purwin has sailed with the cadets of the Massachusetts Maritime Academy, and he hopes to go to sea again. For him, it's a learning process: "To get a feel for a subject, you've got to be there and smell it."

On neither of his voyages was Purwin considered a "necessary" part of the crew, yet those on board appreciated his presence and were intrigued by him. On the Oceanus, *Purwin's interest in their work surely heightened the scientists' and crews' interest in themselves, and helped make Cruise 126 a time not soon forgotten.*

Elizabeth Miller

Warm-Core RINGS of the Gulf Stream

By Terrence Joyce and Peter Wiebe

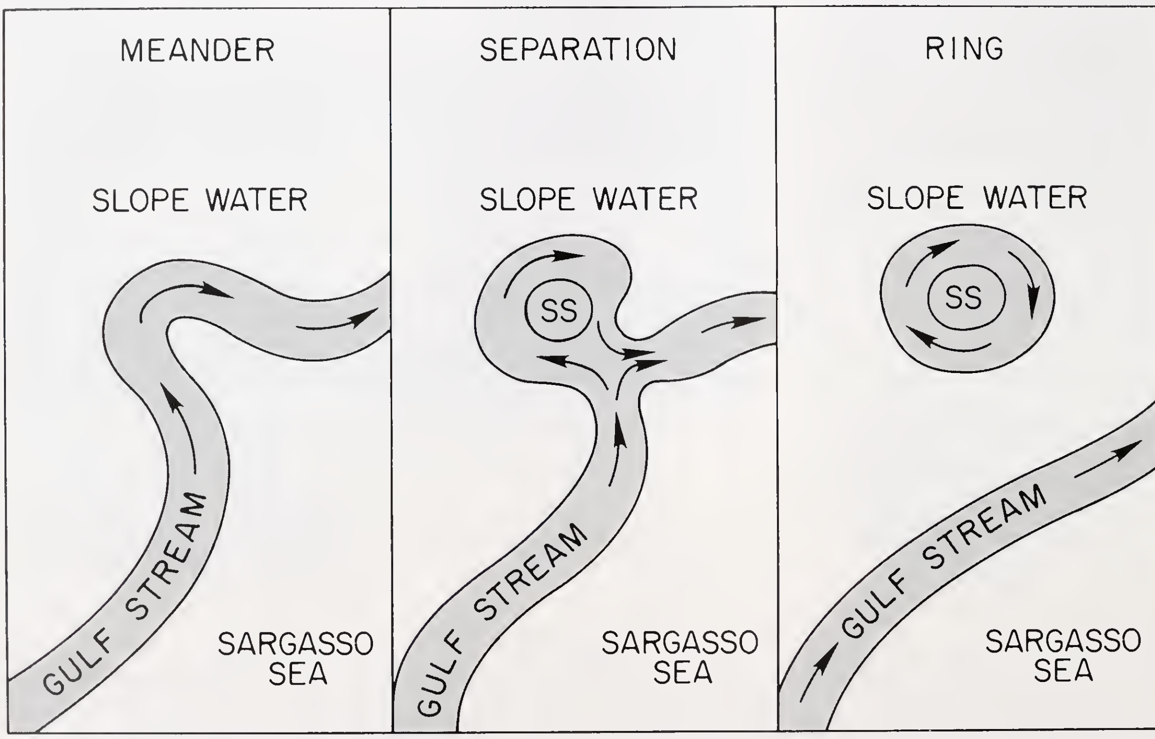
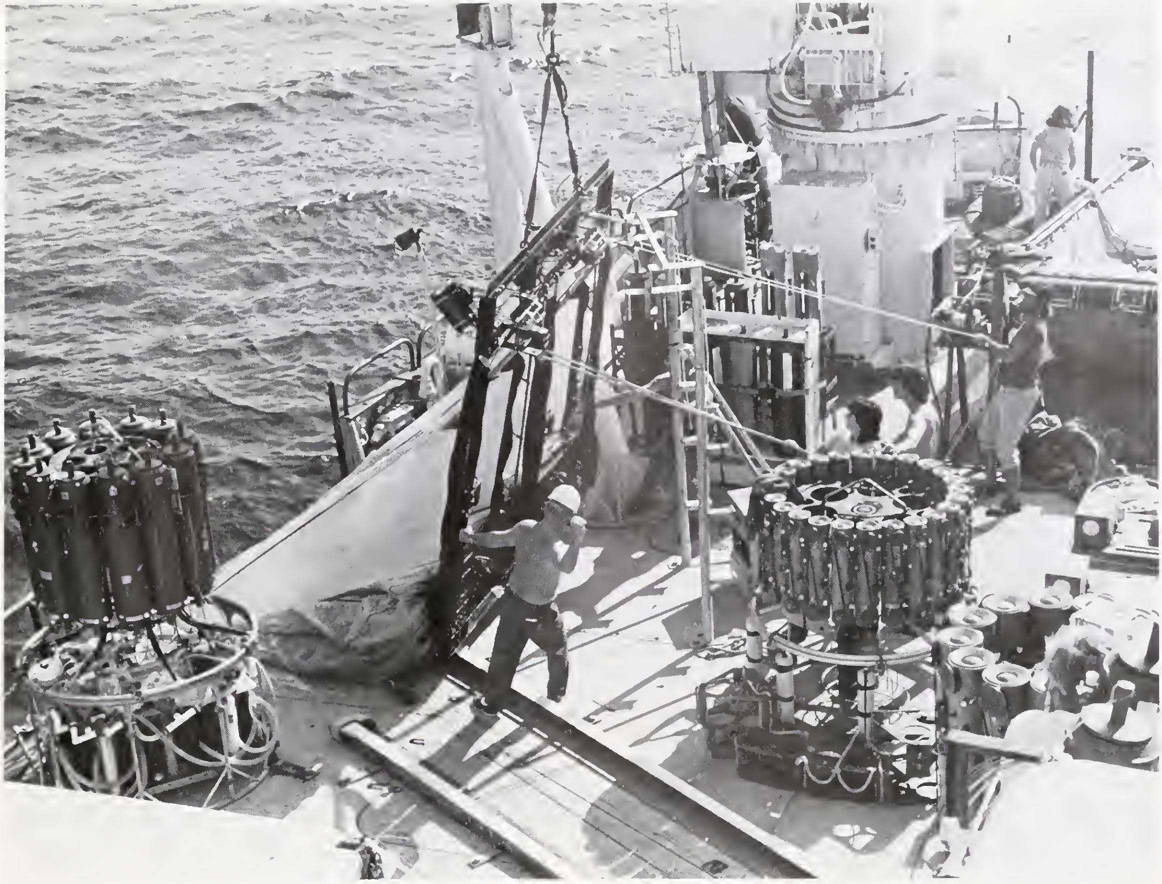


Figure 1. Three stages in the formation of a warm-core ring from a Gulf Stream meander. The core is water from the Sargasso Sea (SS).

We have now reached the halfway point in a major research program to study warm-core rings. Sponsored principally by the National Science Foundation (NSF), the program involves more than 25 principal investigators from 13 research and academic institutions. The National Oceanic and Atmospheric Administration (NOAA) is actively participating through its National Marine Fisheries Service (NMFS) and National Earth Satellite Service (NESS). The National Aeronautics and Space Administration (NASA) funded aircraft overflights during cruises as well as shipboard measurements and data analysis. With a cost of more than $10 million, the program is one of the most comprehensive multidisciplinary projects ever undertaken in ocean studies.

The field phase of the program is complete. All of the investigators (Table 1) are analyzing their data in order to better understand the role rings play in transport and exchange in the region between the shelf water and the Gulf Stream. Among the questions we are trying to answer are: What is the physical structure and motion of a ring? How does it change as it ages? What effects do rings have on the large-scale chemical transport in the region? What are the population distributions in a ring, how do they relate to the environmental factors, and how do they change as the ring ages?

The answers to these scientific questions are of some practical importance. Warm-core rings have been tracked from space by both the U.S. Navy and the NMFS. One reason the Navy is interested in the



The double MOCNESS-1 being brought on board the Knorr *after a successful tow in warm-core ring 82H in September-October of 1982. At upper right is part of the MOCNESS-20 trawl. (Photo by Peter Wiebe)*

James McCarthy of Harvard University doing analytical chemistry associated with his studies of photosynthesis by phytoplankton in warm-core rings, aboard the Atlantis II. *(Photo by Peter Wiebe)*

Table 1. Principal investigators and their primary areas of research in the Warm-Core Rings Program.

1. Experimental and Descriptive Physical Oceanography

Terrence Joyce and Raymond Schmitt, *Woods Hole Oceanographic Institution* — CTD-O_2 and current profiling and mixing studies.

Kevin Leaman and Robert Evans, *University of Miami* — Loran drifter measurements.

Thomas Osborn and Rolf Lueck, *Naval Post Graduate School, Monterey* — turbulent energy dissipation.

2. Chemical Distributions and Processes

James Bishop, *Lamont-Doherty, Columbia University* — particulate flux of chemicals.

Alfred Hanson and Dana Kester, *University of Rhode Island* — investigation of trace metal distributions and speciation.

Dana Kester and Mary Brown, *University of Rhode Island* — nutrient and oxygen studies.

David Schink and Norman Guinasso, *Texas A&M University* — radium-radon studies.

3. Biological Investigations

A. Spatial Patterns

Richard Backus, *Woods Hole Oceanographic Institution* — midwater fish distributions.

Patricia Blackwelder, *Nova University* — coccolithophore abundance and morphology.

Greta Fryxell, *Texas A&M University* — phytoplankton species composition.

Ronald Schlitz and David Mountain, *National Marine Fisheries Service* — fish larvae distributions.

Peter Wiebe, *Woods Hole Oceanographic Institution* — macrozooplankton distribution and life history.

B. Plankton Physiology

Timothy Cowles, *Woods Hole Oceanographic Institution* — macrozooplankton grazing and egg production.

Hugh Ducklow, *Lamont-Doherty, Columbia University* — bacterial production and biomass distribution.

James McCarthy, *Harvard University* — nitrogen nutrient dynamics.

Christopher Garside, *Bigelow Laboratory, Maine* — low-level nitrogen dynamics.

David Nelson, *Oregon State University* — silicon nutrient dynamics.

Michael Roman, *University of Maryland* — microzooplankton grazing studies.

Theodore Smayda and Gary Hitchcock, *University of Rhode Island* — phytoplankton growth studies.

4. Analytical and Numerical Modeling

Glenn Flierl, *Massachusetts Institute of Technology* — circulation and transport modeling.

Joseph Wroblewski, *Dalhousie University* — biological modeling.

5. Remote Sensing

J. W. Chamberlin, *National Marine Fisheries Service* — satellite infrared imagery.

Frank Hoge and Wayne Esaias, *National Aeronautics and Space Administration* — aircraft remote sensing of ocean waters.

Don Olson and Otis Brown, *University of Miami* — remote sensing sea-surface temperature and color.

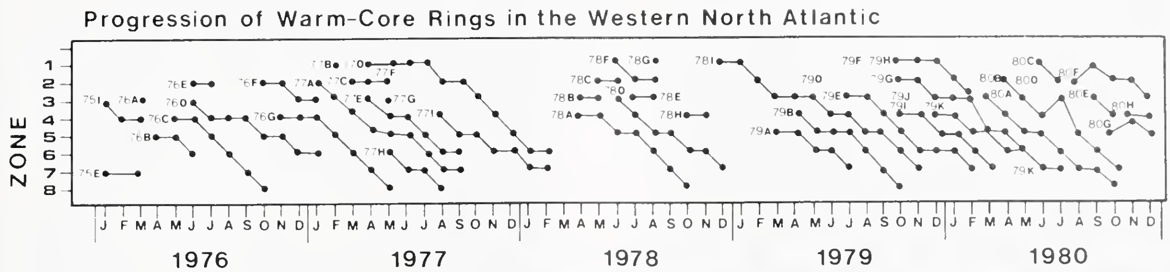
Charles Yentsch and Raymond C. Smith, *Bigelow Laboratory, Maine, University of California, Santa Barbara* — remote sensing of biologically important parameters.

whereabouts of rings is their capacity to alter the underwater propagation of sound. The NMFS is interested in how rings influence the movements of some fish and the survival of fish eggs and larvae. Before the continental margin can be exploited by industry, knowledge of the structure and magnitude of ring currents must be obtained in order to assess the impact of warm-core rings on offshore platforms. The satellite imagery can be thought of as a crude oceanic weather map, indicating the location of anticyclones in the Slope Water. A knowledge of the location and movement of these ocean weather systems can aid in the routing of ships in the region. As long as 10 years ago some crafty navigators in the New York–Bermuda yacht race sought out a ring's current and used it to better their time.

How They Form

Warm-core rings form in the Slope Water region between the North American continental shelf and the Gulf Stream. These rings, or eddies, are bodies of water 100 to 200 kilometers in diameter that result when a meander separates from the Gulf Stream (Figure 1). The warm ring is comprised of a central core, the initial physical, chemical, and biological properties of which originate in the Sargasso Sea. The core of the ring is surrounded and contained by a clockwise rotating remnant of the Gulf Stream with surface current speeds of 50 to 200 centimeters per second. Since the clockwise ring of current surrounds a warm, subtropical core of water, the name "warm-core ring" was suggested by Frederick Fuglister of the Woods Hole Oceanographic Institution (WHOI) to describe these eddies. Cold-core rings are found south of the Gulf Stream in the Sargasso Sea. Both types of rings maintain their identifying properties for a substantial period of time, slowly changing characteristics as they age.

Knowledge about warm-core rings has increased in the last several years because they can be readily observed in satellite infrared images. The U.S. Naval Oceanographic Office and NOAA produce weekly charts of the Gulf Stream/Slope Water region that show the positions of warm and



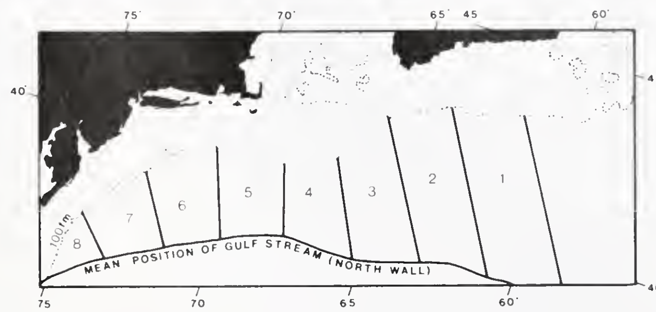


Figure 2. A five-year summary of warm-core rings in Slope Water. Ring location at mid-month is shown for each of eight regions. The rings are denoted by the year of formation and alphabetically by order of formation in a particular year. (From Christ, Friedlander, and Fitzgerald, personal communication)

cold rings. A five-year census of warm-ring activity (Figure 2) indicated the location, lifetime, and identity of 42 different rings.

Warm rings are generated all along the northern edge of the Gulf Stream and drift slowly southwest, in the same direction as the upper-layer flow in the Slope Water, at rates of 3 to 5 kilometers a day. A histogram of ring lifetimes (Figure 3) indicates a mean lifetime of 4.5 months before rings are reabsorbed by the Gulf Stream.

Interestingly, it is not very probable that any ring will have a lifetime of the "average" ring: the histogram shows a bimodal distribution. In the figure, we have shown the number of rings with lifetimes of three or fewer months that are formed and reabsorbed in regions 1 through 3 to the east of the New England seamount chain. One can see that most of the short-lived rings are found in these three regions and that any ring found west of the seamounts usually persists for six to eight months.

Remote sensing imagery is helpful in tracking the surface signature of rings. We know, however, that the currents of the Gulf Stream after they leave the coast at Cape Hatteras can reach to depths of 2 kilometers or more. In order to study the effects of ring aging on the angular momentum, water mass properties, and biota below the surface layer, one must resort to the traditional method of going to sea and collecting *in situ* measurements.

In the last two years, our ring studies have examined at least six different warm-core rings. These are shown in Figure 4. The initial cruise of the program, in September and October of 1981, studied ring 81D. Our main objective on this first cruise was to obtain data that would aid in the planning for a series of four cruises in 1982. What we observed forced us to reassess our conceptual models of warm rings. We had postulated that warm rings would contain a central core of biologically poor Sargasso Sea water, slowly changing with time as the ring matured toward a state similar to that of the

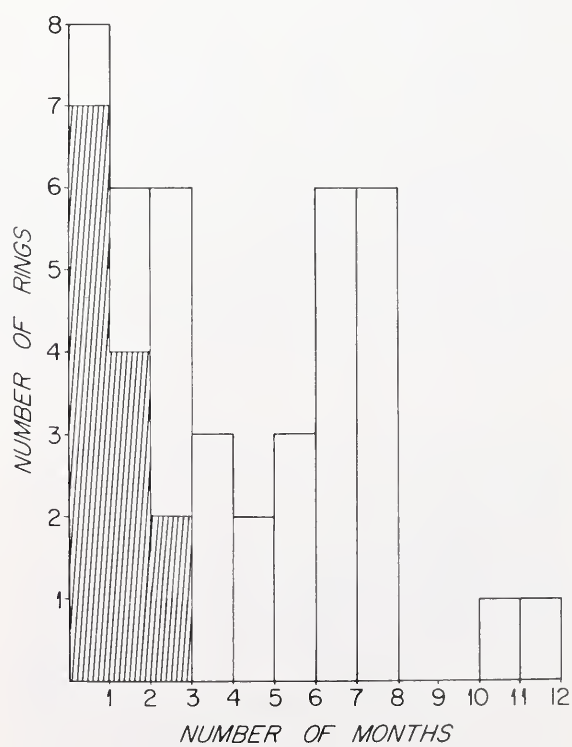


Figure 3. A histogram showing the distribution of ring lifetimes for the warm-ring summary of Figure 2. The dashed region denotes those rings which were formed and reabsorbed in the three regions (1-3) to the east of the New England seamounts and had lifetimes of three months or less.

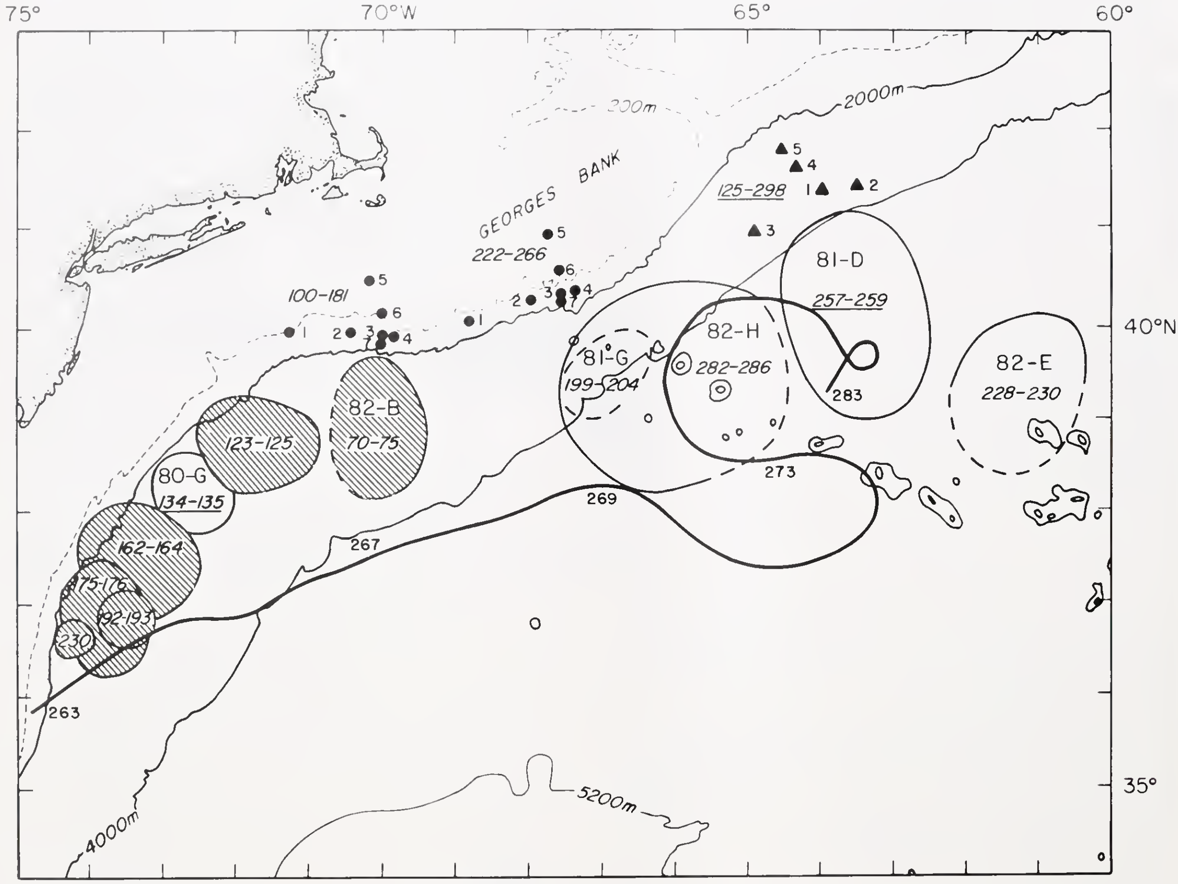


Figure 4. Warm-core rings studied during 1981 and 1982. Though the rings each extend further, their core boundaries here are shown by the line were the 10-degree-Celsius isotherm is 300 meters deep. The Julian days, numbered from Jan. 1, for each survey are shown with the 1981 days underlined. Current meter mooring locations (dots and triangles) and measurement periods are also indicated. The shaded circles at left portray the changing shape and location of ring 82B. The heavy line is the track of the satellite drifter placed in the center of 82B shortly before the ring's demise on day 263, September 19, 1982, when the drifter entered the Gulf Stream (lower left). The drifter eventually re-entered the Slope Water when ring 82H formed in October. Small circles and "fried egg" shapes are contour lines (4,000- and 2,000-meter depths) for the New England seamounts. Dashed lines are extrapolations. (Data for this figure were compiled by M. Stalcup)

surrounding Slope Water. Instead we discovered that a strong interaction with the Gulf Stream could alter the energetics of a ring as much in just 10 days as we anticipated for ring decay over six months.

Furthermore, the chlorophyll, primary productivity, biogenic silica, particulate carbon, and particulate nitrogen were higher in the ring center than in the surrounding Slope Water. The biomass of zooplankton* in the ring core was as large as in the Slope Water. Three research ships cooperated in this first cruise: the *Atlantis II*, operated by WHOI; the *Endeavor*, from the University of Rhode Island; and the *Albatross IV*, a NMFS ship.

A time series study of one ring, named 82B, began in March of 1982. Three multiship cruises followed in April, June, and August, as this ring drifted toward Cape Hatteras, North Carolina, where it eventually was reabsorbed into the Gulf Stream in mid-September. We were fortunate in being able to study this warm-core ring during most of its seven-month life cycle.

Field Studies

On each of the multiship cruises, the vessels carried out complementary tasks. For example, during three of the cruises to ring 82B, there were three NSF-sponsored vessels closely coordinating their sampling programs. The *Endeavor* (Figure 5) was responsible for making expendable bathythermograph (XBT) surveys of the temperature field and for mapping the vertical structure of the horizontal currents in the upper 100 meters, using an acoustic doppler profiler of ocean currents (APOC). Surface drifters, used to provide estimates of ring particle trajectories, were tracked with either the

*Floating or drifting animals, including larvae and eggs, of the open sea.

Long-Range Navigation system (LORAN-C) or the Argos satellite system. Continuous shipboard measurements were made at the ocean surface of temperature, salinity, and plant pigments. Detailed CTD-0_2 (measurements of conductivity, temperature, depth, and oxygen content) and nutrient profiles to the seafloor were made on transects across the ring as well as upstream and downstream of the ring from the continental shelf to the Sargasso Sea. This work was done with sampling bottles in a circular array called a rosette. Bio-optical profiles (with the BOPS system) were taken at each station and included measurements of temperature, salinity, chlorophyll fluorescence, transmissivity, downwelling and upwelling irradiance, and phytoplankton* species composition (from discrete water samples). On some of the warm-core ring cruises, measurements of oceanic turbulence were made to depths of 1,000 meters with the microstructure profiler CAMEL. Current shear** was occasionally measured with expendable current profilers (XCP).

Most of the experimental biological and chemical work was conducted aboard the WHOI vessel *Knorr* (Figure 6). Major stations at locations across the ring were occupied for periods of 12 to 48 hours during which CTD-0_2 rosette casts were made to obtain large volumes of water for use in studies of phytoplankton species composition, bacterial enumeration, and physiological studies. The latter included studies of the incorporation of radioisotope-labeled nutrients, thymidine uptake by bacteria, and trace metal distributions. Net-collected zooplankton and bottle-collected microzooplankton were used in grazing experiments. A multiple opening/closing net and environmental sensing system (MOCNESS) with ¼-square-meter nets sampled microzooplankton in the upper 200 meters at each station. Chlorophyll profiles were obtained with a pump system, while upwelling and downwelling irradiance was measured with a light profiler.

Spatial mapping of macrozooplankton and midwater fishes was carried out aboard the WHOI vessel *Oceanus* (Figure 7) at stations extending from the ring center to the Slope Water using MOCNESS net systems with 1- and 20-square-meter nets. The smaller nets obtained depth-specific samples at 100-meter intervals between depths of 1,000 and 200 meters and at 25-meter intervals from 200 meters deep to the surface. The larger nets were used to fish at 200- to 250-meter intervals between a depth of 1,000 meters and the surface. In addition, large-volume pumping for particulate matter was carried out at 8 to 12 depths in the upper 1,000 meters, using two systems depicted in the figure: the large-volume filtration system (LVFS) and multiple large-volume filtration systems (MULVFS). Other measurements included chlorophyll casts in the upper 200 meters and shallow (upper 600 meters) and deep (to the seafloor) casts for radon-222, radium-226, and radium-228. These data were

*The floating and drifting plants of the open sea.
**Within a current, a difference in the speed of one section in relation to the water adjacent to it.

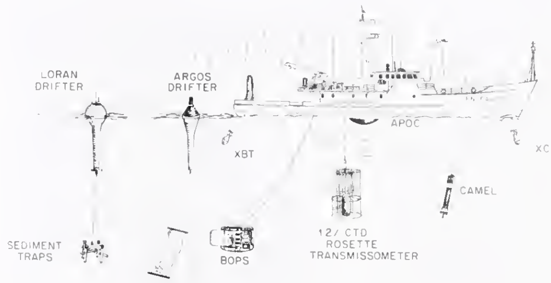


Figure 5. Measurement systems deployed from the University of Rhode Island research vessel Endeavor. *Each sampling bottle in the rosette holds 1.2 liters.*

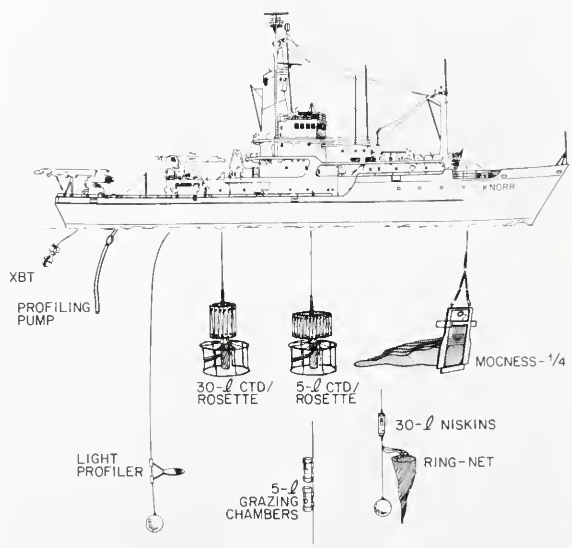


Figure 6. Instrumentation aboard the WHOI-operated research vessel Knorr. *"NISKINS" refers to Niskin bottles. l = liter.*

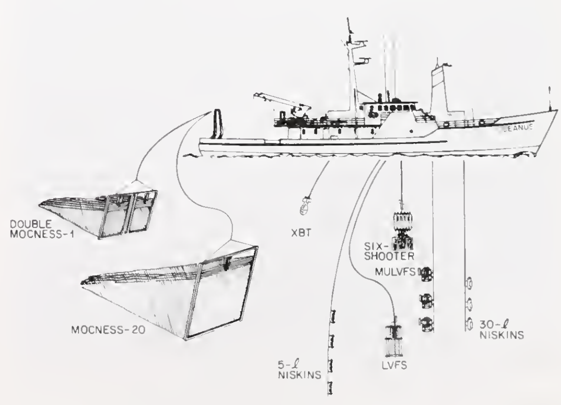


Figure 7. Shipboard instrumentation aboard the WHOI research vessel Oceanus. *l = liter.*

A unit of MULVFS (Multiple Unit Large Volume Filtering System) being attached to a conducting and support cable aboard the Oceanus. (Photo by Peter Wiebe)

The 9-net MOCNESS-¼, entering the water for a 0-to-200-meter oblique tow in a warm-core ring. (Photo by Peter Wiebe)

obtained with 30-liter Niskin bottles deployed either on hydro wire or with the "six shooter," a CTD/rosette that also contained a pump and six filters for the *in situ* extraction of radium-228. The amounts of these radioactive isotopes in the water are useful tracers of different water masses.

On some of the warm-core ring cruises, the NSF ships worked closely with the NMFS ship *Albatross IV* and a NASA Wallops P3 aircraft. Work aboard the *Albatross IV* concentrated on the physical and biological description of the shelf water entrained into the circulation on the eastern side of ring 82B. The aircraft instruments included a light detection and ranging system (LIDAR), a passive infrared thermometer (PRT), a microwave radiometer, and a multichannel ocean color scanner (MOCS).

A description of the results from all of these different measurement techniques is beyond the scope of this brief report. The field phase of our warm-core rings program has only just ended, and synthesis of the many interdisciplinary contributions to the program lies in the future. However, it is possible to describe the major changes in structure and biomass that we observed in ring 82B.

Preliminary Results on 82B

When ring 82B formed in late February, 1982 (Figure 8), it had a core of Sargasso Sea water that contained a deep mixed layer with a temperature near 18 degrees Celsius. When first observed by ship in March, this layer had cooled slightly to about 17.7 degrees. Between March and our first main cruise in April, late winter cooling continued to reduce the core temperature to approximately 15.7 degrees (Figure 9). Subsequently, a shallow seasonal thermocline* developed with surface temperatures exceeding 27.7 degrees by August. The thickness of the core thermostad, or layer of small temperature change, decreased with time, as did the depth of the deep thermocline. A temperature cross-section through 82B in April reveals (Figure 10) the modified warm core of 82B and the structure of the deeper thermocline to depths of 1,500 meters (1 decibar of pressure in seawater is equal to approximately 1 meter). Although not shown in the figure, the warm temperature anomaly of the ring extends below 1,500 meters to the ocean bottom. At the right of the figure the ring is next to the continental slope. At the time of this cross-section, 82B was south of Long Island in the vicinity of Hudson submarine canyon.

The depth of the 10-degree isotherm can be used as an index of ring strength, while the areal extent of water with 10-degree isotherm depths greater than 300 meters is useful as a demarcation of ring size. Both of these quantities, along with the thickness of the thermostad core layer and surface salinity, have been plotted for the ring center versus time in Figure 11. Soon after ring formation, the core temperature decreased to approximately 15.7 degrees Celsius. Thereafter the core temperature remained at this value while the layer thickness decreased with time, as did the 10-degree isotherm

*A layer of sharp temperature change below the ocean's solar-heated surface layer.

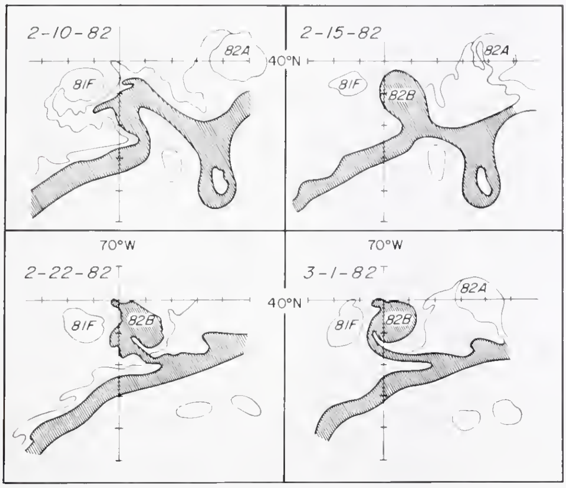


Figure 8. The formation of warm-core ring 82B, between warm rings 81F and 82A. To the south of the Gulf Stream, a cold-core ring is being formed as well, to the east of one already there. These drawings are interpretations of satellite infrared imagery from NOAA polar-orbiting satellites.

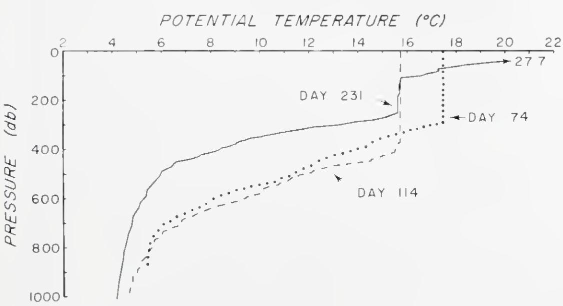


Figure 9. Selected potential temperature profiles in the center of ring 82B. Potential temperature is the temperature a parcel of water would have were it brought to the sea surface without exchange of heat or salt. By August, the temperature of the seasonal thermocline shown in the profile for Day 231 reached 27.7 degrees Celsius. Pressure is measured in decibars (db).

depth and ring diameter. Throughout its life cycle, the surface waters of 82B mixed with the fresher waters of the Slope Water, causing the anomalously salty surface layer of the ring to become less saline. The most rapid change in the physical characteristics of the ring occurred between Julian days 180 and 200 (June 29 and July 18), when 82B suffered a glancing blow from the Gulf Stream. Strong interactions with the Stream not only alter ring properties but also ultimately destroy rings as distinct phenomena. The latter happened to 82B on day 263, when a satellite-tracked surface drifter, deployed in the ring center, began to move quickly to the east.

During the course of its life cycle, chemical and biological characteristics of the ring changed, sometimes very rapidly. The zooplankton biomass (total mass of zooplankton without regard for species composition) can be estimated by vertically integrating net catches and normalizing the result as

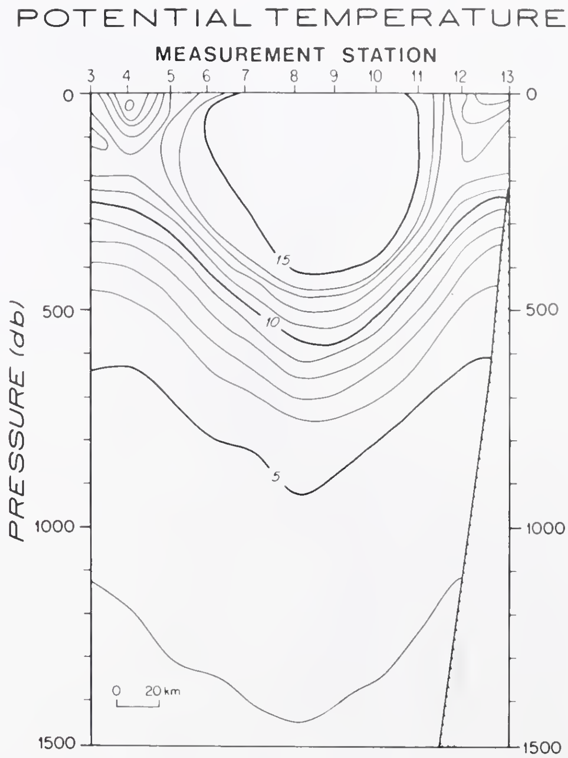


Figure 10. A potential temperature cross-section of ring 82B, made from the research vessel Endeavor *in April of 1982. The contour lines represent degrees Celsius. The slanted line at right is the continental slope. db = decibars.*

a mass per square meter. In March and April, the total biomass in the upper 1,000 meters was significantly lower in the center of the ring than in the adjacent Slope Water (Figure 12). By April, the biomass had increased in both the ring center and the Slope Water: in the ring center, a 50-percent increase was observed, in contrast to an increase by a factor of three in the Slope Water, where a major springtime bloom of phytoplankton accounted for the change. It was apparent by the end of the April cruise that the surface water was warming and beginning to stratify, and that the ring core was ready for a spring bloom of phytoplankton. By the time of our June cruise, the phytoplankton biomass had sharply increased in the ring center, whereas in the Slope Water a decline had taken place; the zooplankton biomass was higher inside the ring. The difference in biomass between the ring core and Slope Water was insignificant after day 200. At this time, the ring was substantially reduced in size and in close proximity to the Gulf Stream. The biological variability in Slope Water was large and the biomass levels high, mainly because of one station in which the jellyfish *Pelagia pelagia* dominated the zooplankton catch. The biomass of ring 82B was substantially higher than that of either the Sargasso Sea or the Gulf Stream, both of which were sampled on the August cruise.

In a comparison of the evolution of the standing crops of zooplankton in warm- and cold-core rings, it appears that warm-core rings

Launching a CTD/Rosette system during the first of the warm-core ring cruises in 1981, aboard the Atlantis II. (Photo by Peter Wiebe)

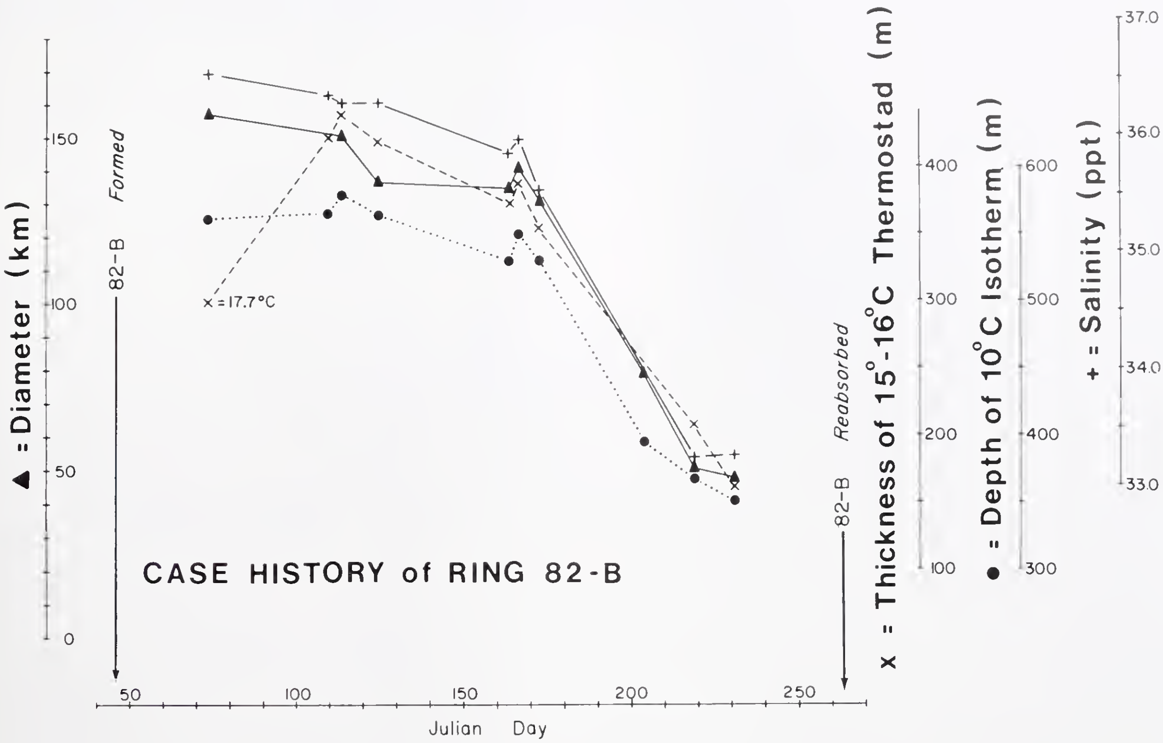


Figure 11. A history of 82B observations, showing the changes in the diameter of the ring, the depth of the 10-degree-Celsius isotherm, the thickness of the thermostad (the layer maintaining a temperature of 15 to 16 degrees Celsius), and the surface salinity at the center of the ring. km = kilometers, m = meters, ppt = parts per thousand. (Data for this figure were compiled by R. Schmitt and M. Stalcup.)

Ray Smith, aboard the Endeavor *in April of 1982, talking via satellite to scientists on the research vessels* Oceanus *and* Knorr, *and at the remote sensing facility in Miami, about a satellite infrared image (in foreground) of ring 82B, which was just received. The image was sent with a telecopier, using the satellite telecommunications link. (Photo by Terrence Joyce)*

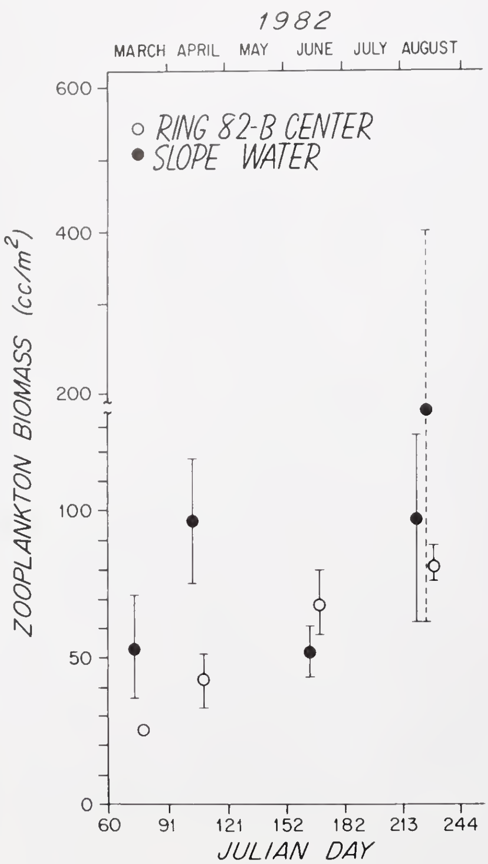


Figure 12. Temporal changes in zooplankton biomass, measured in cubic centimeters per square meter (cc/m^2) in the upper 1,000 meters near the center of ring 82B and in nearby Slope Water. The circles and bars denote the mean values and range, respectively, from several samplings. The single circle represents a single plankton tow. The dashed line for the Slope Water in August includes the large catch of jellyfish discussed in the text.

increase their biomass levels to a parity with the Slope Water faster than cold-core rings decrease their biomass to Sargasso Sea levels. We suspect that this is a result of a higher frequency of interactions that warm-core rings undergo with the Gulf Stream and the continental shelf waters.

Although rings deserve study in their own right, they present a particularly good opportunity to study the mechanisms that regulate ocean ecologies. Because salinity, temperature, and other variables change at different rates as a ring decays, it may be possible to learn which variables are strongly related to changes in the abundance of different species.

The multidisciplinary study of warm-core Gulf Stream rings described in this article is continuing. It is our expectation that our efforts will result in significantly better understanding of the many processes occurring in the world's oceans, a substantial number of which require a multidisciplinary examination. At the very least we will have gained a great deal of knowledge about processes taking place in energetic eddies. This should be of considerable value, since rings or ring-like phenomena have been discovered throughout the world's oceans wherever major current systems are found.

Terrence Joyce is an Associate Scientist in the Department of Physical Oceanography at the Woods Hole Oceanographic Institution. Peter Wiebe is also at the Institution, as an Associate Scientist in the Department of Biology. Both are on the executive committee of the Warm-Core Rings Program.

Acknowledgments
We wish to acknowledge the support of the above-mentioned funding agencies, which supported our research. Our thanks also go to the many scientists and support personnel who made the field program possible. Deserving special note are A. Morton, who headed the program office and solved many of the logistical nightmares that arose, and P. Eden, who was of great assistance with communication during the field work.

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Trends in Neurobiology Using Marine Models

by William J. Adelman, Jr.

A freshwater lake in New England is closed to swimming after a large fish kill. The taking of shellfish along the Maine coast is prohibited during an invasion of red tide. Scientists flock to marine laboratories worldwide to study the giant nerve fiber of the squid.

These statements read like headlines in the daily press, and all are true. Neurotoxins, acting on sodium channels in nerve fibers, cause the fish kill and red tide toxicity of the first two "headlines." The third results from the usefulness of the giant nerve cells of certain marine organisms in the study of neuronal function. Investigators may be able to solve the mystery of Alzheimer's disease, which

Myxicola infundibulum, *a species of marine polychaete worm. These specimens were obtained from Canada's Bay of Fundy and photographed in a seawater aquarium. The worms are extended above the mud with their branchial filaments spread fan-like for food capture. When a worm is excited, the fan closes and the worm retracts under the mud inside its mucous tube. A single axon transmits the nerve messages for this withdrawal response. Much of what we know about neurofilaments has been learned from the study of this giant axon. (Photo by Priscilla Roslansky)* produces premature senility in humans, by studying the nerve cells, or neurons, of squid, lobsters, and marine worms. And there is hope that this research will eventually provide answers concerning many other nerve and muscle disorders.

Blue-green algae undergo periods of excessive growth in some lakes. One such species, *Aphanizomenon flos-aqua*, produces one of the most poisonous substances known, a toxin that directly attacks the basic mechanism by which the neurons of higher organisms produce the impulses that carry on the function of nervous systems (see *Oceanus*, Vol. 19, No. 2, 1976). It is now known that this toxin is either similar or identical to the toxin produced by the red-tide organism in the ocean. Humans swimming in lakes rich in this toxin are in the same jeopardy as people eating shellfish contaminated with red-tide toxin. Despite these dangers, this toxin has been most useful in revealing the mechanism by which nerve fibers conduct information. In this regard, the humble squid has been a favorite species for study.

The giant nerve fiber, or axon, of the squid has played a key role in helping scientists understand the workings of all nerve cells. Using squid giant axons, we have studied the mechanisms whereby nerve fibers generate electrical impulses and use them to send information along biological transmission lines. Several recent developments in nerve cell research bring us even closer to understanding the molecular basis for electrical events in nerve cells.

Another area of nerve research is the study of how a neuron internally transports materials important to its function and maintenance. This is one of the most amazing mechanisms known in living organisms. As in other nerve research, the squid, along with lobsters, horseshoe crabs, and three different marine worms, has become an important tool because of the large size of its axons. These creatures have figured prominently in unfolding the wonder of the structural basis for neuroplasmic transport.

Why are marine invertebrate species so important in developing and testing ideas about the structure, function, and pathology of nervous systems in both invertebrates and vertebrates, including humans? All species have components manufactured according to age-old chemical principles and biophysical operations. Many marine species represent earlier stages in the evolutionary development of biological complexity, and therefore often have fairly simple structures. These species, then, can be used as models of the complicated systems of higher species. Study of simpler biological systems often gives us insight into the function of our own species.

Electrical Messages

Excitable cells, such as neurons and muscle fibers, generate and conduct electrical messages, or impulses. Systematic study of the characteristics of these impulses indicates that they all share a common mechanism based on a universal type of chemical structure. A nerve impulse is the summation in time and space of a set of minute, discrete events. While these events are somewhat random in terms of how long they continue in an active state, the impulses that encode neural messages arise from these pseudo-random events. What this means is that orderly events proceed from sets of fluctuating events.

Several other neural activities have similar characteristics. Independent studies by C. F. Stevens of Yale University and Bernard Katz of University College, in London, and their colleagues, of the transmission of information between nerve cells and between nerve endings and effector organs, such as muscles and glands, have shown that there are small unitary events in the post-neural (muscle) membranes; these make up the synchronized larger events that transfer information between the cells. It is now clear that there is a general similarity among all bioelectrical events; this finding supports the idea that the molecular structures giving rise to such

The squid, Loligo pealei, *has played a key role in helping scientists understand the workings of all nerve cells. (Photo courtesy of the Marine Biological Laboratory)* activity are all rather similar. Therefore, the differences among cell types, tissues, and species is more quantitative than qualitative.

It is now widely accepted that bioelectrical events are produced by a class of molecules called channels, imbedded in excitable cell membranes. These channels admit, from time to time, small quantities of specific ions (charged particles). The ions move from outside the cell to its interior, or vice versa, and give rise to extremely small (but measurable) electrical currents. Irrespective of the type of excitable cell or the species from which the cell was obtained, these currents are similar. As well, regardless of the cell type or species under study, the membrane channel molecules react similarly with a variety of chemical agents, toxins, and drugs. This implies that the chemical makeup and structure of these channel molecules is roughly the same for the whole animal kingdom. There are several types of channels, each serving a given function in any one species; the same types are found in many species. For example, we expect that the so-called "sodium channel" in the membrane of a squid giant axon is similar to that found in motor axons in human legs.

During the first half of the 20th century, numerous analyses of membranes from living cells indicated that they are composed mainly of lipids (containing fatty acids); the lipid molecules are arranged in a bilayer array, with their hydrophilic (water-liking) heads on the inner and outer surfaces, sandwiching the molecules, and their hydrocarbon tails in between. Such a membrane would be two molecules thick, about 6 nanometers (6 billionths of a meter) across. The lipid cell membrane defines the outer limit of a cell and provides a relatively impermeable barrier separating the cell contents from the outside environment. For most water-soluble substances to move through this lipid barrier, specialized mechanisms must exist. One such mechanism is channel admittance.

A channel can be thought of as a tunnel with a lumen (inner space) having an environment favorable to water and water-soluble materials (Figure 1). If the channel lumen is very small, and if the chemical groups lining the lumen are very specific, admitting only some substances, then the channel can be selective, allowing only certain molecules of a small size to pass through. If the lumen can be controlled, so that some of the time it is closed and some of the time it is open, it can act as a valve or gate. Figure 2 illustrates this concept. Actually, we now know that channels can be controlled by the electrical field across them and/or by reactions with certain specific chemical activators. In the former case, we say that the channel gating is voltage-dependent; in the latter, we say it is chemically activated. Many of the properties of channels can be inferred from their interaction with neurotoxins, several of which have been derived from marine animal sources.

Single Channels

In 1967, two scientists, Paul Mueller and Donald Rudin, working at the Eastern Pennsylvania Pyschiatric Institute in Philadelphia, successfully produced artificial bilayer membranes from synthetic lipids. They discovered that these membranes could be made to respond in a manner similar to living nerve membranes by incorporating a specific impurity (excitability-inducing material, or EIM) into the bilayer. When stimulated, the membrane produced responses similar to nerve impulses. When EIM is present in an artificial bilayer, discrete units of current across the membrane can be recorded, suggesting that these currents are being produced by "channels." By 1970, scientists learned how to incorporate a single molecule of EIM into a membrane. That made it possible to record a single unit of current (Figure 3), corresponding to the open state of a single channel.

As the understanding of channel-forming chemicals grew, the search for equivalent behaviors and structures in real cell membranes intensified. In 1976, Erwin Neher and Bert Sackman, working at

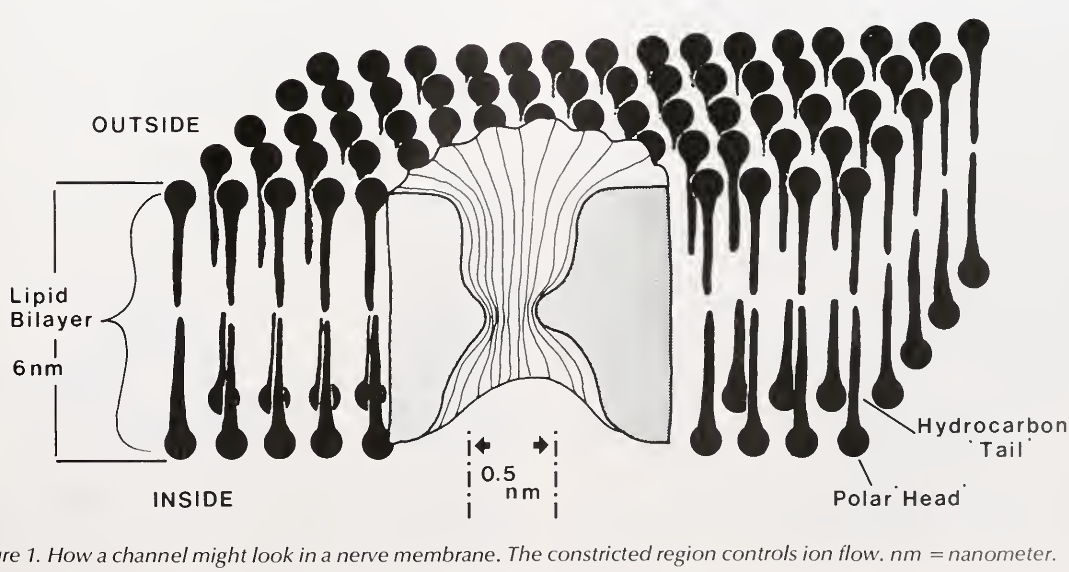


Figure 1. How a channel might look in a nerve membrane. The constricted region controls ion flow. nm = nanometer.

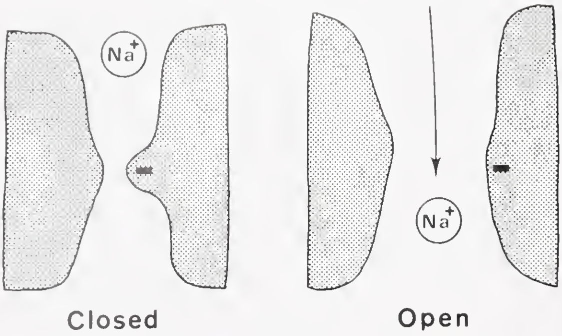


Figure 2. How a sodium ion (Na^+) might pass through a gated channel. In the closed state, a sodium ion is prevented from passing through the channel. In the open state, the sodium ion can pass through the channel, as the "gate" is in the open position.

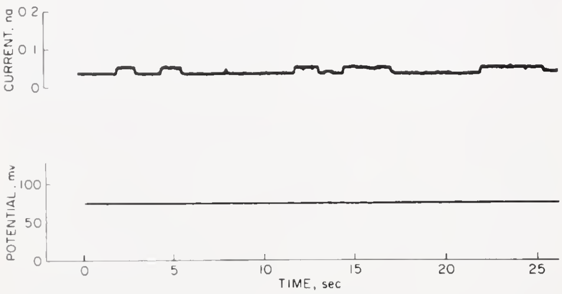


Figure 3. Discrete current steps recorded for a single EIM channel. The upper trace shows recorded current through the artificial bilayer membrane. The lower trace shows the simultaneously recorded constant voltage through the same membrane. The voltage across the membrane is held constant (clamped) by means of an external electrical circuit. na=nanoamps; mv=millivolts; sec=seconds. (From Ehrenstein and others, 1970)

West Germany's Max Planck Institute, presented a method for measuring the bioelectric currents passing through the channels in living membranes. Their method involves isolating a small patch of membrane by pressing a tiny conducting pipet against the membrane surface, then measuring the electrical current running into the pipet. The results resemble those of single-channel currents in artificial bilayers. Using this method, conductances in channels activated by acetylcholine have been measured in amphibian, mammalian, and human muscles (Figure 4); voltage-dependent, potassium-ion-selective channel currents have been measured in the squid giant axon (Figure 5); and sodium channel currents have been measured in muscle membranes.

It appears that channels exist in all living excitable membranes. There are at least 10 classes of channels, and the channels found in human membranes bear a striking resemblance to some found in other species. Many laboratories are attempting to isolate, purify, and then reconstitute biological channels in membranes, and it would

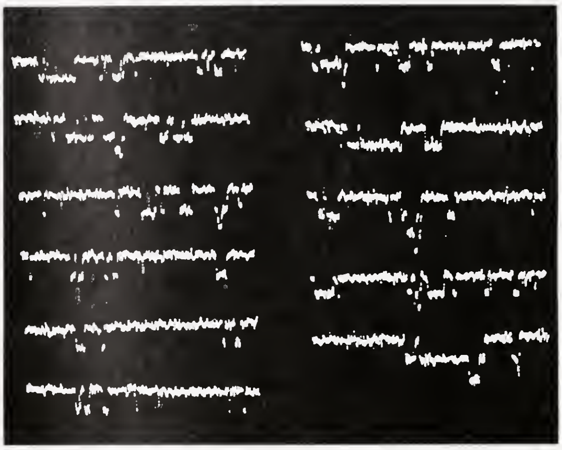


Figure 4. Single-channel current jumps recorded at the postsynaptic membrane of tissue-cultured human muscle. (From Lecar, 1981)

seem to be only a question of time before we can construct molecular models for each type.

Axoplasmic Transport

In addition to conducting rapid impulses to activate muscle tissue, nerve cells synthesize many materials necessary to the maintenance of their structure and function. These syntheses take place in specialized regions called cell bodies. Cell bodies contain the nucleus of the cell and associated structures. The nucleus encloses the genetic material, specifically deoxyribonucleic acid (DNA). The cell body is rich in ribonucleic acid (RNA) and several enzyme systems known to act as catalysts in protein synthesis.

The materials synthesized in cell bodies are used in distant parts of the nerve cell. A typical nerve cell has a long axon extending outward over distances many times greater than the width of the main cell body. Evidently, nerve cells have mechanisms for delivering synthesized materials over great distances within each cell's cytoplasm. As diffusion is a very slow process, the term "axoplasmic transport" is used to imply that these movements, though much slower than a nerve impulse, do exceed the rates generally associated with passive diffusion.

In our work, we are trying to visualize the structure or structures involved in this kind of transport by using electron microscopy. We also are interested in seeing actual movement in living cells, using traditional light microscopy, and in correlating these movements with the underlying structures that might be responsible for or associated with this transport.

Because of the very long length of most axons and dendrites (Figure 6), nerve cells have developed a special mechanism for internally transporting materials and organelles (Figure 7). The transport mechanism is especially important for moving synaptic vesicles, which contain the transmitter substances that are released at nerve endings to carry the nerve message from one cell to another. Synaptic vesicles are produced in the cell body; they move the

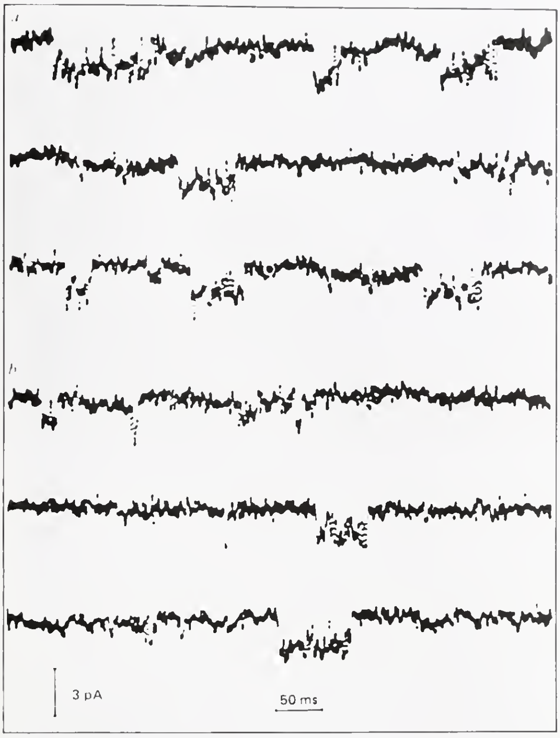


Figure 5. Discrete current jumps for single potassium channels in the squid giant axon membrane. The upper three traces were recorded at –25 millivolt membrane potential. (The voltage inside the axon was 25 millivolts less than outside.) The lower three traces were recorded at –35 millivolts. The steps are more frequent at –25 millivolts than at –35 millivolts and indicate that the channel is voltage-dependent. pA =picoamps; ms =milliseconds. (From Conti and Neher, 1980)

length of the cell at a certain speed until they reach the region of the nerve ending. There, their contents are released through the nerve membrane, spilling transmitter chemicals into the space between the cell of origin and the target cell. These releases are controlled by electrical messages arriving at the ending. Empty vesicles, vesicle membranes, and other materials then move from the nerve ending back to the cell body.

The hypothesis illustrated in Figure 7 seems too restrictive in terms of our most recent evidence. We see no indication of specialized filaments that transport attached organelles and particles. However, we support the notion that some sort of cross-bridge activity is responsible for organelle and particle movement. The exact nature of the cross-bridge action remains unknown at this writing. Several possibilities are under investigation: 1) cyclic attachment and detachment of the bridges to highly specific sites on the organelles and particles, producing motion in a rachet-like manner; 2) ballistic impelling of organelles and particles with the cross-bridges beating in a manner similar to cilia; and 3) the transport filament hypothesis as described in Figure 7. Regardless of which of these mechanisms is correct, it is clear that adenosine tri-phosphate (ATP) is required as an energy source for activity and that divalent ions, such as Ca^{++}, have a role in activating the mechanism. The mechanism(s) must also account for movement of different particles in different directions, with different rates.

Material movement toward the nerve ending is called anterograde or orthograde transport, and away from the nerve ending, retrograde transport. In either direction, material transport goes at one of two distinct rates: fast transport on the order of hundreds of millimeters per day, or slow transport at a few millimeters per day.

The general method for measuring orthograde transport involves injecting a labeled (radioactive) material into a region of the nervous system rich in nerve cell bodies. If an amino acid labeled with radioactive tritium is taken up by the cell bodies and incorporated into proteins and polypeptides, the movement of these substances can be followed down the axons by following the spread of radioactivity.

Sampling the radioactivity along the length of the nerve cell some time after the injection reveals that, though the highest level of activity is in the region of injection, away from this region there are high levels up to some specific distance, where the activity falls off to a very low level. A wavefront of activity exists at this point on the axon. Later, that wavefront will be observed to have moved further from the point of injection. The distance the wavefront moves in a certain time span is the velocity of transport.

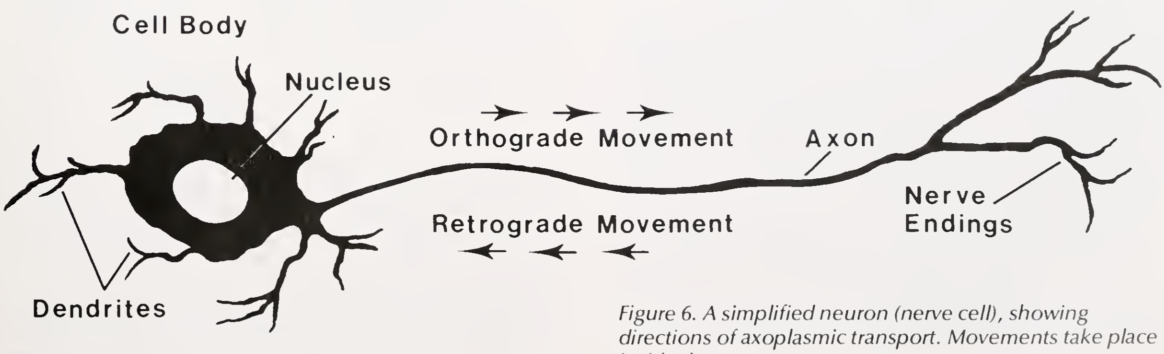


Figure 6. A simplified neuron (nerve cell), showing directions of axoplasmic transport. Movements take place inside the axon.

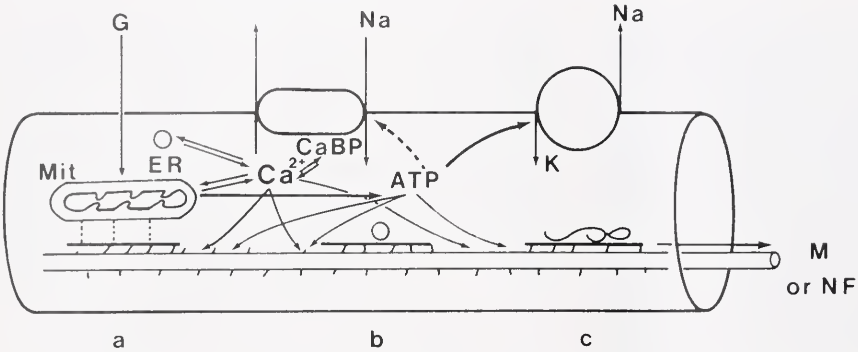


Figure 7. The transport filament hypothesis. Glucose (G) enters the fiber, and after oxidative phosphorylation in a mitochondrion (Mit), adenosine tri-phosphate (ATP) is produced. A pool of ATP supplies energy to the sodium pump, controlling the level of sodium (Na) and potassium (K) ions in the fiber, and also to the microtubule side-arms for the transport filaments. The side-arms, or cross-bridges, are shown as black bars to which various components are bound and so carried down the fiber. The components transported include the mitochondria (a), attaching temporarily (dashed lines) to the transport filament, thus giving rise to fast back-and-forth movement with a slow forward progression; particulates or vesicles (b), shown as a circle; and soluble protein or polypeptides (c), shown as a folded or globular configuration. Simpler molecules are also bound to the transport filaments. Thus a wide range of components is transported at the same rate. The cross-bridges between the transport filament and the microtubules (M) presumably act, when supplied by ATP, in a fashion similar to the sliding filament theory of muscle. In addition, a calcium ion (Ca^{2+}) is shown participating in transport filament movement. Regulation of this ion is shown with sequestration in a mitochondrion and an endoplasmic reticulum (ER), and binding to protein (CaBP). A sodium-calcium ion exchange or a calcium pump is also present in the membrane. NF stands for neurofilaments. (From Ochs, 1981)

A variety of methods has been used to study the movement of organelles and particles inside nerve fibers. Most of these methods use video cameras to capture images of living material under microscopes, then enhance these images, and present them in electronic form for storage on magnetic tape.

With light microscopes it is possible to see the movement of mitochondria, large vesicles, and other particles. The observed particle movements usually run parallel to the long axis of the nerve fiber. Several different rates exist for these movements in single squid giant axons, and there are different kinds of movement, ranging from smooth-flowing to oscillatory. Axoplasmic transport even proceeds in extruded axoplasm, leading us to infer that this transport does not necessarily depend on the electrical activity of the nerve membrane.

Axons are filled with longitudinally oriented filamentous elements, called neurofilaments and neurotubules. We think these are linked together by periodically distributed, transversely oriented "bridges," forming a well-defined three-dimensional grid structure. Figure 8 illustrates how we visualize the grid's structure; the model is based on our electron micrograph studies of the cytoplasm of the squid giant axon (Figure 9) and is similar to that apparent in the cytoplasm of several types of vertebrate neurons. Marine species have evolved two major subsets of this structure. In phylogenetically old species, such as horseshoe crabs and lobsters, the long longitudinal filaments appear to be only neurotubules. Figure 10 is an electron micrograph of such a structure. In some polychaete marine worms, such as those of the genera *Myxicola* and *Sabella*, the longitudinal fibers appear to be almost exclusively neurofilaments with a few neurotubules.

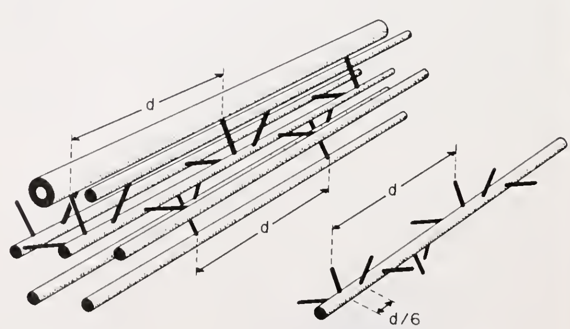
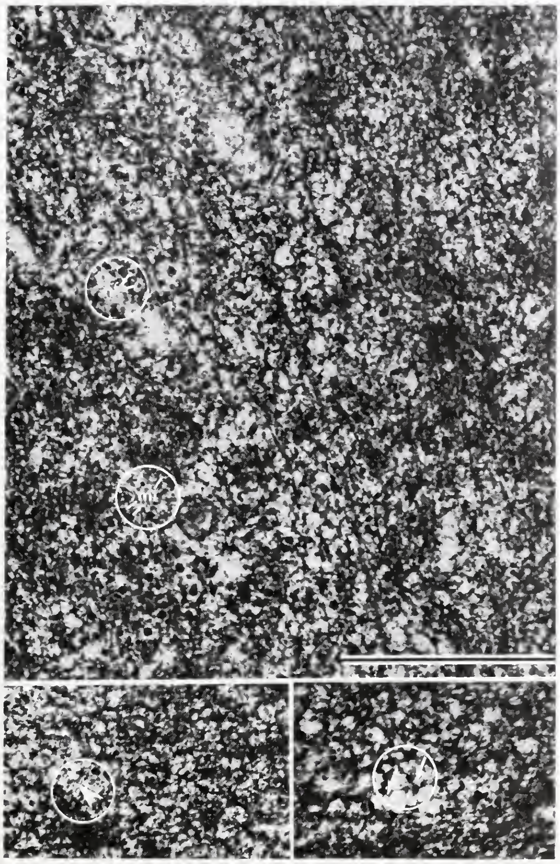


Figure 8. The neuroplasmic lattice, illustrating a possible arrangement of the cross-bridges between longitudinal elements. Although not shown, similar bridges link these elements to cytoplasmic membrane surfaces and are observed running between neurotubules. In the arrangement shown, the fundamental interval (d) is six times the standard space (approximately 43 nanometers) between bridges. (From Hodge and Adelman, 1983)

(a)



(b)

(c)

Figure 9. A relatively thick (0.1–0.2 micrometer) transverse section (a) of a giant axon from a squid (genus Loligo*), showing a neuroplasmic network containing both microtubules (mt) and neurofilaments (nf) linked transversely by numerous bridges. An underlying structural configuration appears to be present, but it is mostly masked by other structures except in areas like those shown in (b) and (c). In (c), the clear doubled arrangement of bridges (arrows) is interpreted as being due to a slightly oblique angle of view. Note the tendency for a hexagonal pattern (arrowhead) to appear, such as in (b). Sections (a) and (b) are magnified 51,300 times. Section (c) is magnified 68,400 times. The scale marker is 1 micrometer long. (From Hodge and Adelman, 1980)*

Regardless of species, neurotubules are about 25 nanometers in diameter and have hollow centers. The neurofilaments appear to be about 10 nanometers in diameter and have a solid appearance (though they might be hollow). Cross-bridges between these longitudinal fibers are about 2.5 nanometers in diameter and radiate out from a longitudinal element to its nearest neighbors. The diagram in Figure 8 shows a hypothetical six-fold screw-axis symmetry of the cross-bridges. By comparing squid axons with both arthropod and marine-worm axons, the relative roles of neurotubules and neurofilaments may be assessed.

Motion of organelles and particles inside axons might result from cross-bridge movement. It appears likely that cross-bridges are constantly

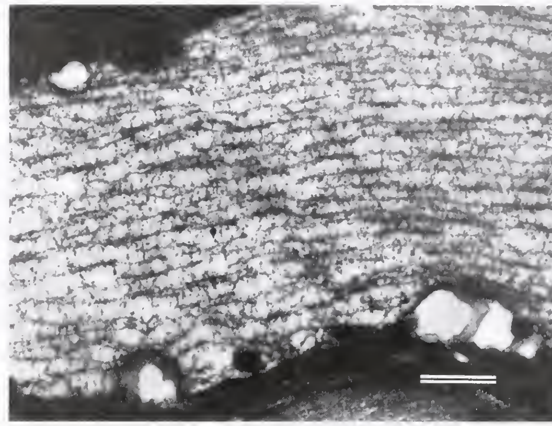


Figure 10. Electron micrograph of an oblique longitudinal section through a ventral cord axon of a lobster (genus Homarus*). The axon occupies most of the picture and is lighter than the surrounding tissue. Notice the long elements running roughly from right to left and the thin, roughly vertical cross-bridges connecting these elements together. The longitudinal elements appear hollow and are identified as neurotubules. The scale in the lower right-hand corner indicates a distance of 1 micrometer. (From Hodge and Adelman, unpublished)*

attaching and detaching themselves from neighboring neurotubules and filaments so that they beat in a manner analogous to the oars of an ancient galley. Such "beating" can be imagined as providing a propellant force to organelles and particles in the spaces between longitudinal filaments.

Our visualizations of organelle and particle movements in living axons support this suggestion. We mostly see movements that follow tracks along the long axis of the axon. We occasionally see particles "switch" or "jump" tracks. In fixed preparations (dead tissue) examined in the electron microscope, particles and organelles always appear near or between the neurofilaments and neurotubules. We even see "trains" of vesicles lined up in a row in the space between adjacent filaments. These findings support our proposal that particle movement occurs in the intralattice spaces.

Axoplasmic Structure and Human Disease

Alzheimer's disease is one of the more debilitating of human neurological diseases, one of the senile dementias. It has a peculiar pathology involving neurofibrillary tangles. The neurons are swollen, and contain skeins of abnormally twisted neurofibrils and neurotubules. While the cause of Alzheimer's disease is not yet known, several suggestions have been made. One of these implicates aluminum, because this element is found in higher-than-normal concentration in the cytoplasm of neurons from patients with Alzheimer's disease. By using the axon preparations made from the marine species mentioned previously, we should be able to test and examine aluminum and other proposed agents of Alzheimer's disease for their specific neuroplasmic effects.

A genetically or environmentally abnormal tubulin (the major protein of neurotubules) may be implicated in Alzheimer's disease. Now that we can visualize axoplasmic transport, macromolecular structure, and basic biochemistry in the same nerve cell, we may be able to locate and define the exact neuronal defect that occurs in this disease. The three classes of neuroplasmic lattice — found in marine arthropods, worms, and cephalopods — provide specific model systems for testing the role of each element in these lattices.

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The Marginal Ice Zone Experiment

by Robin D. Muench

The earth's polar regions are characterized by vast expanses of floating sea ice. In the South, this ice surrounds the Antarctic continent. In the North, ice covers the central Arctic Ocean and, depending on the season, large portions of the Bering and Greenland seas (Figure 1). The outer boundaries of the polar ice caps are the marginal ice zones (MIZs). The MIZs are sites of highly energetic interactions among the atmosphere, the ice, and the ocean; they are thought to play a pivotal role in the dynamics of global climatology; and they heavily impact high-latitude fishery and petroleum development. To study these phenomena, the Marginal Ice Zone Experiment (MIZEX) was organized.

Angular, broken ice floes above are typical of the Bering Sea marginal ice zone and reflect the recent effects of sea swell, which has caused flexure of the ice and consequent breakage. The dark areas on the ice surface show recent flooding by seawater, in contrast to the brightness of the fresh snow cover elsewhere. Despite air temperatures well below the freezing point, water temperatures above −1° Celsius (the approximate melting point for ice of the observed salinity) caused this ice to melt rapidly. (Photo by author) Inset, the National Oceanic and Atmospheric Administration (NOAA) ship Discoverer *follows in the wake of the U.S. Coast Guard icebreaker* Westwind *during marginal ice zone field studies in the Bering Sea in February of 1983. Both vessels participated, along with specially instrumented aircraft from NOAA and the National Aeronautics and Space Administration (NASA). (Photo by John T. Gunn, SAI/Northwest)*

Development of the Program

During the 1970s, Arctic oceanographic and sea-ice research efforts were focused on the high Arctic. This focus was typified by the Arctic Ice Dynamics Joint Experiment (AIDJEX), which led to major advances in our understanding of ice behavior inside large fields of sea ice. At the same time, it was becoming apparent through other field studies that the more difficult and possibly more significant problems were associated with the vast, shifting, marginal ice zones. In 1974, the U.S. National Academy of Sciences recommended a focusing of attention on the Arctic MIZ and intensive theoretical studies of physical processes that control the location of the sea-ice edge. In 1981, the Joint Scientific Committee of the World Climate Research Program recommended a

Figure 1. Heavy lines indicate maximum and minimum locations of the Northern Hemisphere ice edge for mid-winter (late February), thus defining the mid-winter Northern Hemisphere marginal ice zone. These locations were compiled using 1953-to-1977 data by Walsh and Johnson (1979). Stippling indicates the approximate locations of the Bering Sea (a) and Greenland Sea (b) MIZEX study regions. The cross marks the North Pole.

comprehensive study of MIZ physical processes so that these processes could be adequately represented in climate models.

The recently accelerated exploitation of mineral resources, especially petroleum, in the Arctic has contributed to the growing interest in MIZ research. Commercial development is especially intensive in the Bering Sea and requires operations within, as well as shipment of materials through, the MIZ. Thus, an improved understanding of MIZ processes is needed to support pertinent engineering decisions. For example, detailed information is needed on ice thickness and motion in the Bering Sea MIZ, so that oil drilling structures can be designed to withstand ice stresses. Several oil companies are at the forefront of MIZ research, particularly in terms of the Beaufort Sea, which becomes a marginal ice zone in summer.

MIZs also are areas of high biological productivity with lucrative commercial fisheries. The southeastern Bering Sea is a major fishing ground in the Northern Hemisphere and, in winter, is part of the MIZ. The richest fisheries in the North Atlantic lie close to the ice margin. A more thorough understanding is needed of the oceanographic and biological processes of the MIZ, so that these biologically fruitful areas can be more effectively managed.

Finally, the Arctic MIZ is of interest from a strategic viewpoint. Both the Greenland and Bering seas provide access to the Arctic Ocean. Patterns of oceanic temperature, salinity, and current affect naval operations, as does the ice itself. MIZ-associated temperature and salinity fields strongly influence acoustic propagation. Effective naval operations in the ice margins are dependent on a more complete understanding of these processes.

Research activities during the last decade have led to definition of the most significant MIZ-related problems, and the increasing interest in MIZ processes has prompted development of a major study program. A series of workshops, commencing with one held in Voss, Norway, in 1980, led to the development of an international program to study MIZ processes. This program, which focuses on the Bering and East Greenland seas, is MIZEX.

What Is Known

Planning for MIZEX included the compilation of existing information concerning the MIZs. The following generalities were made:

- *The MIZs are regions of highly energetic and unique interactions among air, ice, and water.*
- *The MIZs are characterized by large horizontal variations in physical properties, such as water temperature and salinity, and in physical processes, such as mixing (Figure 2).*
- *The MIZs are highly time-dependent, with processes occurring in time scales ranging from less than tidal to interannual.*

For descriptive purposes, it is useful to categorize MIZ processes into those occurring primarily within the ocean, within the ice, or within the atmosphere.

MIZ Oceanic Phenomena

The MIZs are areas of dramatic horizontal change: oceanic temperature, salinity, and current speeds vary abruptly from ice-covered to ice-free regions. Waters underlying the ice tend to be colder and less saline than those to seaward. These gradients in water temperature and salinity can be associated with current shear.* The inner boundary of the East Greenland Current, with its strong current shear, falls within the MIZ, and a northwestward current "jet" is associated with the Bering Sea ice margin. In both cases, the horizontal property gradients suggest oceanic frontal behavior. Eddy-like structures that typically occur along fronts have been observed along the East Greenland Sea ice margin. Such frontal processes are of interest because they may strongly affect lateral heat transfer across the MIZ.

Vertical gradations in temperature and salinity are also observed in the MIZ. Melting ice releases low-salinity water to the ocean surface layer along the ice margin. This lowers the water density and causes formation of a stable upper layer that may inhibit mixing. Short-term freezing events, conversely, increase the concentration of brine in the upper layer, thus increasing the density so that vertical convective mixing occurs. Strong and highly variable buoyant inputs to the upper ocean layer make the MIZ a fruitful region in which to study oceanic mixing processes.

*Within a current, a difference in the speed of one section in relation to the water adjacent to it.

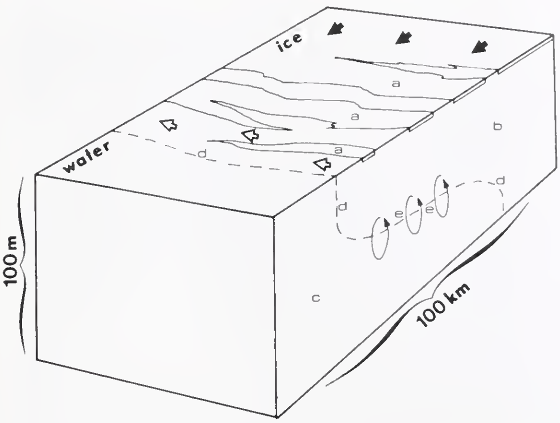

Figure 2. Distinctive oceanographic features are associated with marginal ice zones (MIZs). In this schematic, the dark, solid arrows indicate the seaward movement of ice that typifies a MIZ. Upon entering a MIZ, ice tends to diverge and break up into band-like features (a) separated by open water that further accelerates melting. Melting of the ice, which has a low salt content relative to that of seawater, leads to formation of an upper oceanic layer (b) which is less saline and colder than the deeper layer (c). The separation between these two layers forms a frontal region (d). Vertical mixing processes (e) and currents along the ice edge (open arrows) are associated with the frontal structure. The distances indicate typical length scales. m = meters, km = kilometers.

The MIZ regions, being vertically stratified, can support internal waves and vertical current shear. Detailed observations of temperature and salinity suggest that warmer oceanic waters commonly enter an MIZ along planes of equal density between layers of colder water from beneath the ice. Complex mixing processes contribute to the vertical exchange of heat within the water column.

Pack ice can act as a "lid" that nearly prevents the effect of wind on the ocean surface and sharply reduces air/sea exchange of heat and moisture. These contrasts may partially account for ice-edge upwelling, the transport of nutrient-rich, deep ocean water to upper layers near the ice. Upwelling may be one reason for the high biological productivity of the MIZ.

MIZ Sea Ice Phenomena

As a rule, there is more melting than freezing at marginal ice zones. This is especially apparent in the Bering Sea, where ice forms primarily to the north, moves southwestward under the influence of northeast winds, and melts along the edge. Exceptions may occur in early winter, however, when freezing occurs at the ice edge. The presence of warmer water to seaward of the ice margin accelerates melting of ice that is moved there by wind or by a large-scale shift of the ice.

The structure of the ice within the MIZ is heavily influenced by ocean swell (Figure 3). Short surface waves generated by local storm activity are rapidly attenuated by the ice cover. The longer swell can propagate for a considerable distance beneath the ice: in the Bering Sea, appreciable swell has been observed some 80 kilometers north of the ice edge. Swell tends to break up large ice floes into smaller ones, hence the MIZ is characterized by decreasing floe size as open water is approached. The degree of breakage may in turn determine the local impact of wind. Highly fractured MIZ ice may allow a more effective transfer of wind stress to the underlying water than either less-fractured pack or the ice-free surface to seaward.

Finally, ice in the MIZ is often characterized by streamer or band-like ice formations that extend from the solid pack out into open water. These are formed by the interactions (not well understood as yet) of winds, surface waves, possibly internal waves, and the ice. The bands are felt to be particularly significant because they may hasten melting at the outer limit of the MIZ by facilitating the movement of ice away from the pack into warmer water.

MIZ Meteorological Phenomena

The meteorological processes of most interest in the context of the MIZ are those which control the exchange of momentum, heat, moisture, and radiative energy between the atmosphere, the ice, and the ocean. Ice exerts a considerable influence on the characteristics of the lower atmosphere. The atmosphere "feels" the boundary between ice and open water as a sharp interface across which discontinuities in physical processes occur. For example, exchange of heat between the ocean and the atmosphere may be 100 times greater over open water than in the presence of an ice cover. During off-ice winds, the air receives a tremendously increased input of heat as soon as it passes from ice to open water. This results in rapid warming of the lower atmosphere, with attendant changes in surface wind speed and wind stress exerted upon the water.

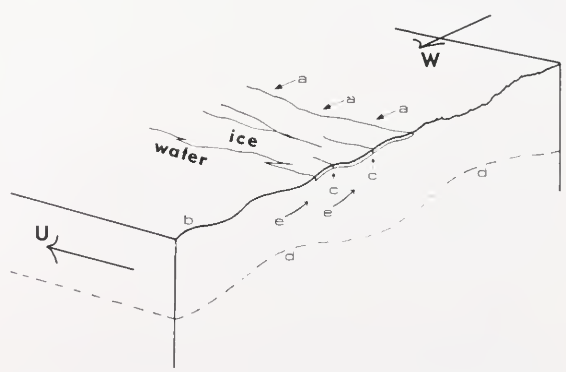

Figure 3. During periods of seaward (off-ice) winds (W), the primary force (a) acting on the ice in a marginal ice zone is a combination of wind drag and wave-induced stress. Surface waves develop in the water between ice bands. Long ocean swells (b) penetrate the ice without exerting appreciable horizontal force, but associated vertical motions flex the ice and cause it to fracture (c) so that it breaks into smaller pieces. Ocean currents (U) exert frictional drag on the ice. Additional stress can be caused by interactions between the ice and internal waves (d), which are present in the stratified water. Finally, heat is continually supplied from the water column (e) and leads to melting.

This ice floe in the Bering Sea marginal ice zone was instrumented to measure ablation, or melting, of the ice and illustrates most of the remote instrumentation that was used on the ice during MIZEX West. A radar transponder (a) and reflector (difficult to discern against the people in the background) atop a pole (b) allow the floe to be continually tracked by the ship. A wave disc buoy (c) contains an accelerometer that measures wave-induced ice motion; these data are then telemetered to a receiver on the ship. An internally recording anemometer (d) measures winds over the floe. The vertical staffs (e) are instruments designed to measure vertical melting rate. Not shown is a current meter that was suspended beneath the floe to measure relative ice/water motion. The numerous spheres are flotation devices that are attached to the instruments in case the floe breaks up before the ship can retrieve the gear. (Photo by author)

Some Scientific Questions

There are numerous hypotheses about the behavior of marginal ice zones, but our total knowledge falls far short of a well-integrated theory explaining these zones. We must address at least the following points:

Oceanographic Questions

- *What are the spatial and temporal structures of the oceanic frontal systems associated with the MIZs?*
- *How do these frontal systems respond to melting ice, sea-floor topography, and other regional oceanic features?*
- *How do frontal processes, such as eddy formation, contribute to horizontal and vertical transfer of heat and salt in the MIZ?*
- *What is the nature and frequency of upwelling along the MIZ, and how does it affect biological productivity?*
- *How do vertical mixing processes in the upper ocean layer respond to varying wind, ice cover, meltwater input, and current conditions?*
- *What is the nature of the internal wave field in the MIZ, and how does it interact with other processes, such as mixing?*

Sea Ice Questions

- *What are the roles of internal ice stress, winds, currents, and waves in MIZ ice dynamics?*
- *What oceanic and atmospheric features, such as winds, currents, and heat fluxes, control the advance and retreat of ice in the MIZ, and what is the relative importance of each?*
- *What are the distributions of ice thickness and floe size in the MIZ, and how are they influenced by ocean surface waves?*
- *How important are such MIZ features as bands in controlling ice-edge movement, and how do these features develop?*

Meteorological Questions

- *What are the surface wind stresses acting on the ice and ocean in the MIZ, and how are they influenced by ice distribution?*
- *How are broad-scale meteorological patterns related to winds in or near the MIZ?*
- *Do jet-like winds or seabreezes occur in association with the MIZ, and what are their dynamics?*

The Program

The Marginal Ice Zone Experiment has been designed to address the scientific questions just listed. It will focus on two Arctic MIZ regions: the winter Bering Sea (MIZEX West) and the East Greenland Sea (MIZEX East). The two regions were chosen because they share many MIZ properties, while representing a broad spectrum of conditions. The Bering Sea MIZ overlies a shallow (100 meters deep) continental shelf region with very low average current speeds and first-year ice typically less than 1 meter thick. The East Greenland Sea MIZ overlies a continental slope with depths varying from less than 200 meters to more than 1,500 meters. Flowing through this region is the East Greenland Current, which has considerably higher current speeds and greater shear than are encountered in the Bering Sea. East Greenland Sea ice is a mixture of first-year and multi-year Arctic pack that can be several meters thick. Despite these differences, both regions have MIZ-associated features, such as frontal structure and ice-edge bands.

The research program involves a combination of field studies, analyses, and numerical modeling. The field studies simultaneously examine as many processes as possible, through the use of surface vessels and moored recording instrumentation, such as current meters, satellites, and specially instrumented aircraft (Figure 4). Ice-strengthened vessels are used seaward of the outer limit of the ice to observe oceanographic and atmospheric parameters. Icebreaking vessels are used within the ice itself, to obtain coordinated observations and to serve as study platforms from which the ice can be characterized. Helicopters operating from the various vessels provide local reconnaissance and

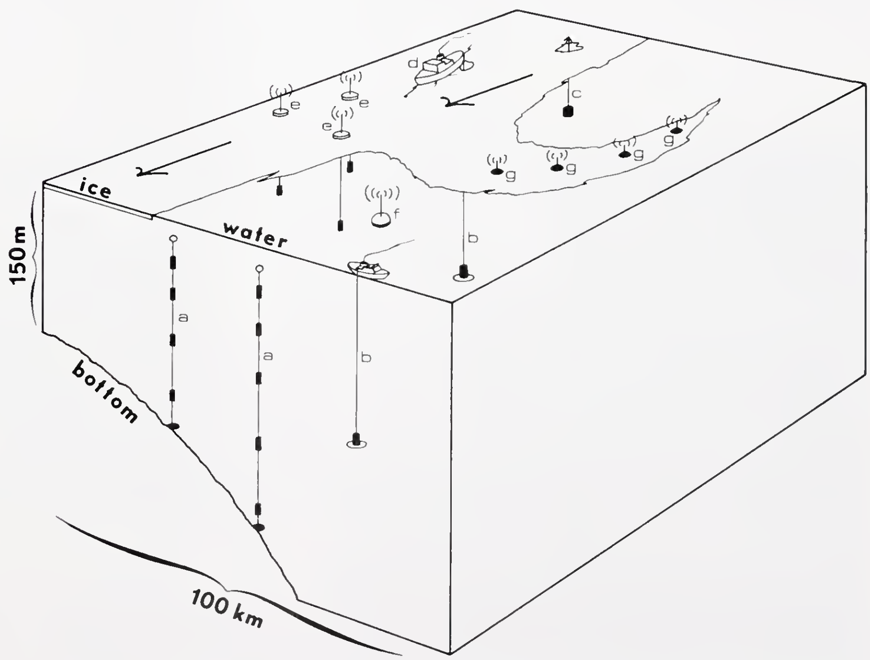

Figure 4. This illustrates many features of a field experiment to study the MIZ in the Greenland Sea. The MIZ in this region overlies the continental slope, as indicated by the steeply sloping bottom. An overall southward motion of ice and water is indicated by the arrows. Subsurface current moorings (a) record water motions. Conductivity/temperature/depth systems (b) operated from surface vessels determine the oceanic temperature and salinity fields. A profiling instrument (c) operated from an ice station measures fluctuating currents, temperature, and salinity that might be associated with internal waves or mixing processes. The ice-related portion of the experiment centers on a vessel (d) drifting with the ice and providing helicopter support for deploying additional instrumentation on the ice. A triangular array of telemetering devices (e) monitors ice motion relative to the water and transmits the data to the drifting vessel. A wave buoy (f) measures surface waves seaward of the ice. Radar transponders (g) track the motion of an eddy-like feature. Throughout this measurement program, remote-sensing aircraft fly over the region and accumulate information on ice and meteorological parameters. m = meters, k = kilometers.

deployment of personnel and equipment on the ice. Long-range aircraft fly over the experimental regions to provide larger-scale characterization of the ice as well as to measure selected atmospheric and ice parameters.

Planning strategy calls for a phased series of field experiments, the first of which has already taken place in the Bering Sea MIZ (mid-winter, 1982-83). A second field effort will take place in the East Greenland Sea in mid-summer, 1983. Many of the field procedures used in this experiment will make use of information gained during the Bering Sea study. A third and considerably larger experiment is planned for the East Greenland MIZ in the summer of 1984. Tentative plans call for an experiment in the ice-formation region of the Bering Sea in the winter of 1984-85, and for a major East Greenland experiment in 1987. These experiments will broaden in scope as the researchers approach an ideal model of MIZ systems.

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Acknowledgment
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profile Karl K. Turekian

Portrait by Charles Kerins

Academic Gladiator

by Ben McKelway

The ideas fly like bullets, rapid fire. In 30 minutes, the group has discussed possible methods of recycling trash, mining trace elements, tracking radioactive waste through groundwater, and using a fossilized tooth to determine the chemistry of a prehistoric lake. The lake discussion in turn sparks a debate over how much oxygen was in the earth's early atmosphere.

This is "Coffee Time" in the geochemistry lab at Yale University, New Haven, Connecticut. The master of ceremonies for the daily event is Karl Karekin Turekian, the university's respected Henry Barnard Davis Professor of Geology and Geophysics. There are arguments, full of puns and put-downs, and a joke is usually what changes the subject. Graduate students, researchers, and sometimes other professors make up the group, donuts and coffee in hand.

Now storming against a preposterous new theory he read about the day before, now leaping from his chair to re-enact, laughing, the pitcher's mound scuffle of last night's New York Yankees game, now grabbing the chalk and pretending to graph the buoyancy of a hippopotamus, Turekian entertains. But what seems at first glance like a Marx Brothers routine is actually as important as any class. It is here that students are kept on their toes, here that new experiments are framed, and here that a fresh and useful idea can arise unexpectedly from the interplay of sharp minds. It is the creative edge of science. Some call it "the gladiator school of geochemistry," because Turekian comes out swinging.

"Perennial conflict is the essence of science and is a desirable thing," declares this burly man with a deep voice and a gruff, impatient exterior. How many freshmen, timid or insecure, have been scared off before they could see the teddy bear beneath? He speaks quickly, with such enthusiasm that a riot of words comes tumbling, as if expelled for not keeping up. Though a conservative dresser (dark suit, blue shirt, and tie), he's not the type for starch and creases; he could tame a new suit by lunchtime. His vitality makes his modesty a surprise. Passionate about his love for the earth, he is reluctant to talk about his own accomplishments. Instead he steers the conversation toward others in the field, stressing that every scientist builds on the work of others.

In an age when a scientist can become a talk-show celebrity and important political decisions are made on the basis of scientific speculation, the public may get the impression that a good scientist fights for his own ideas. According to scientific tradition, however, a scientist is supposed to propose a hypothesis and then try to *disprove* it, with help from his or her colleagues. In fact, any theory should be assumed wrong until validated by other experiments. A theory that is eventually proven wrong can still be a great contribution to science, for the insight it provides and the probing it provokes.

Turekian has done his share of providing and provoking. For his doctoral thesis under J. Laurence Kulp at Columbia University in New York, he was assigned to investigate a new proposition that the ratio of strontium isotopes in calcium carbonate (limestone) deposits could be used as a "chronometer" to determine the age of seabed sediments anywhere on earth. When it was shown, early on, that this ratio was not a reliable dating tool, he changed his thesis direction to find out why. "That is what started me out trying to understand the whole crust of the earth, the mantle of the earth, volcanism, magmatic fractionation, erosion, weathering, et cetera," he says. "Every time I asked a question, more and more I realized how little I knew about each of those processes."

It was variations in the way the earth's crust developed that precluded the ratio as a dating tool, but understanding the principles behind those variations was even more important, to science in general and to Turekian's career in particular. His dedication to that understanding has given him a global view. "He's known for his breadth of knowledge," says James Heirtzler, a geophysicist at the Woods Hole Oceanographic Institution. "The combination of that and his personality makes him a pivotal point in marine geochemistry." Another colleague, Wallace Broecker, describes him as a catalyst, an innovator who tends to get a new branch of research started and then moves on to something else. "He's a guy with tremendous amounts of imagination and enthusiasm," says Broecker, a former schoolmate of Turekian and now Newberry Professor of Geochemistry at Columbia's Lamont-Doherty Geological Observatory.

"I've actually stopped in the middle of a lecture and said, 'Oh my God, it's not like that at all!' "

As a child, Turekian listened to a weekly radio show called "The Cavalcade of America," which featured stories about famous Americans, including scientists and inventors. The show was interspersed with commercials from its sponsor, the Du Pont Co., a chemical manufacturer. "You always had the overtones that if you were a chemist you were really mainstream—that was tops—there was nothing better to be in this whole world than a chemist," he recalls. For his interest in the earth, he credits his father, who had been sent to America by his ill-fated Armenian parents so that he would be spared from future massacres like the one in 1896, the year he was born. On learning that most of his family had been killed in World War I, his father enlisted in the U.S. Army. Ten years later he was stricken with multiple sclerosis, and he spent long hours talking with Karl, his only child, about his adventures as an infantry sergeant in France and as a Surfman in the Life Saving Service of the Coast Guard stationed on Cuttyhunk Island, Massachusetts, and about, as his son now puts it, "fishing and Prince Edward Island and the time he had to go out and stop the rum runners and all this seagoing stuff." Young Karl started collecting maps.

From his Armenian Protestant mother, the boy acquired his religious training. He even considered the ministry as a career; he had come to feel that to abandon his religion, which his forefathers had died for, would be to abandon his people as well. He chose Wheaton College, in Illinois, after serving in the U.S. Navy as an electronics technician at the end of World War II. He majored in chemistry.

From Wheaton, the summa cum laude graduate was recruited by Columbia, where he immersed himself in a full courseload of mathematics, physics, chemistry, and geology. He spent the summer of 1953 out in Montana. Having grown up in New York City, he had to learn to ride a horse before he could collect rocks from a remote plateau. In 1955, he and some other Columbia graduate students, together with professors Norman Newell and John Imbrie, taught themselves scuba diving in the swimming pool of a Brooklyn hotel and embarked the next summer on an expedition to study the Bahama Banks. It was an intensive study; the group spent parts of the next two years sampling and analyzing the water, the sediments, and the flora and fauna. Curious about near-shore sediment dynamics, Turekian mapped the salinity and temperature structure of Bimini Basin "just for the fun of it." Years later an English researcher used the map as the basis for his thesis on the ecology of the area. "Weird things like that happen all the time," says Turekian. He spent the major part of the summer of 1956 in Greenland, studying the ice cap and the rocks along the west coast of that large glaciated island.

It was as a Lecturer at Columbia College in the mid-1950s that Turekian discovered another great love — teaching. His affinity for his students is plain to see. As we walked across the Yale campus together, he ran into one pupil after another, greeting each with genuine interest in the latest news of a project, a paper, a problem, a triumph. He seems buoyed by human contact, and says he's the one getting the education. "The willingness to engage an idea, working out distortions and inconsistencies, which you are forced to do when you teach, is what makes you a good teacher ultimately," he says. "I've actually stopped in the middle of a lecture and said, 'Oh my God, it's not like that at all!' "

The evolution of "Coffee Time" also can be traced to Columbia, where the graduate students would work all week and all day Saturday until 3:00 in the afternoon and then meet for the weekly seminar, run by Kulp. "It was a free-for-all," he recalls fondly. "We used to prepare like mad for it, too. Oh, boy we used to get mad at each other and yell and scream. It's painful when it's happening, but in the long term it's a very educational process. Then we'd go to church on Sunday morning."

Today's "Coffee Time" is a direct descendant of that Columbia seminar: "Anybody who is involved is stripped of any special role. Everybody is subject to attack. And you're absolutely required, if not automatically able, to show ignorance on the subject, which is very important. There is too much of a tendency for professors and students to masquerade behind appearing to know, and the greatest breakthroughs are when you don't know, or when you thought you knew and all of a sudden someone says something that shatters what you thought you knew was correct. And that's the most productive part of that free-for-all, the exchange that goes on. It's not a guaranteed thing. If it were predictable, then there wouldn't be the spontaneity. It has had an effect on kids, there's no doubt about that. It certainly has an effect on me, so that is why I consider it a success. But it's not programmed; it's not anything you could write down somewhere and give it a course number or something. It's probably the most important teaching I do at Yale, or have done ever."

With his arrival at Yale in 1956, geochemistry started there in earnest. Assigned to the basement of a building without hot water, fume hoods, or even an old-fashioned calculator, he virtually built his entire laboratory. His work since then has enhanced Yale's reputation as well as his own.

Using radiocarbon dating methods, Broecker, Turekian, and the late Bruce Heezen established the chronology for the last ice age, and the paper they published on the subject in 1958 is still a bench mark. Again, Turekian says he did it "for the fun of it." Turekian's research on strontium enabled the Atomic Energy Commission to guess at the amount of strontium 90 that was likely to end up in human bones as the result of atomic bomb tests in the atmosphere, before there were enough data on strontium 90 to be sure. This work also had an archaeological application. Because the ocean is so high in strontium, the strontium-to-calcium ratio in a fossilized bone could tell an investigator whether the bone was from a marine animal or a land animal. But when he began to see papers claiming the ratio could be used to determine whole ecologies and even eating habits, Turekian wasted no time. He analyzed fossilized shells from various locations to prove that, over time, groundwater could have altered the ratio too much for it to lead to specific conclusions.

Turekian teamed up with Broecker for the first integrated geochemical sampling cruise, in 1961 aboard the Lamont-Doherty research vessel *Vema*. This was the antecedent to the Geochemical Ocean Sections Study (GEOSECS). Because they were doing seismic refraction work, the vessel was loaded with depth charges and dynamite marked "U.S. NAVY." Just south of Cuba, they were buzzed by a Cuban fighter plane that seemed to miss the ship by inches. If strafed, the ship would have blown sky high, but the Cubans had a right to be suspicious — three months later came the Bay of Pigs invasion.

Broecker remembers kidding his friend that year about the long list of prerequisites he had set for a wife. At 33, Turekian was still holding out for an intelligent, beautiful, Protestant woman of Armenian descent who was, of course, unattached and willing to marry *him*. His friends all thought the chances of their tenacious colleague finding such a woman were slim at best. But he found her. Her name is Roxanne, and she is presently Learning Consultant and Curriculum Coordinator for a private school in New Haven. The couple, married in 1962, has two children: Karla, 16, and Vaughan (named for Karl's father), 11.

"The reason you should get mad at shoddiness is that you have to watch out for it in your own life."

Getting back to geochemical archaeology, a longtime interest for this geochemical generalist, Turekian employed dating techniques, using radioactive isotopes, for bones, tools, and pottery, and wrote of a way to tell if ancient nickel-rich alloys were made with ore from meteorites. He also studied meteorites as part of an attempt to figure out how the earth got its oceans and its atmosphere. After years of controversy, false starts, and dead ends, he and others concluded that the newly formed earth must have been veneered by material resembling a type of meteorite called a carbonaceous chondrite, which contains the right compounds for a degassing theory in which heat-triggered reactions led to the escape of gasses from within the earth.

Today he has a grant from the National Science Foundation to establish whether or not the thin layers of iridium found in some ancient sediments were fallout from a huge meteorite hitting the earth. Recently the iridium band has been hailed in the popular press as the final explanation for the rapid extinction of dinosaurs and other species of that time, the argument being that the cloud of dust after such an impact would have blocked sunlight. Turekian is skeptical, noting paleobotanists indicate that fossils of most plant species seem to cross the time boundary without significant change. His group will be measuring minute quantities of two osmium isotopes that are always found with iridium. The ratio of these two isotopes in meteorites generally differs from the ratio in rocks of crustal origin.

Turekian's serious interest in meteorites can serve to illustrate his serious impatience with shoddiness of any kind. Our interview was interrupted by a call from a magazine copy editor who wanted to read him a manuscript on the Wethersfield (1982) meteorite exhibit at Yale's Peabody Museum of Natural History. As Curator of Meteorites for the museum, Turekian supervised construction of the exhibit. Turekian said the article had some inaccuracies. For one thing, he didn't like the meteorite's color described as "black and gray." Only the chipped portions were gray.

"You wouldn't say a watermelon was green and red," Turekian told the man. "You would say it's green on the outside and red inside."

When the editor wouldn't make another change, Turekian lost his temper. "Obviously I care about the earth and I care about things that are done well, and I don't like verbal garbage being poured on my head!" he shouted into the phone.

"The reason you should get mad at shoddiness is that you have to watch out for it in your own life," he explained later.

Strife is a sign of life to the man. He believes that solid science must be hardened from molten controversy. He enjoys the wrangling, and expects it from others. Convinced that some undersea fracture zones are worth considering for disposal sites if high-level radioactive waste is ever buried in the ocean floor, he and a former student of his, Peter Rona, wrote a paper on the subject. They noted that waste deposited at such deep-water sites would be buried quickly by continual avalanches of sediment. Although one member of a group planning subseabed disposal told him the idea would not be considered (possibly because the group felt the site was unstable and impossible to monitor), Turekian wants to formally know why. "I guess the group didn't like the idea, because no one ever bothers quoting that paper," he muses. "They should have quoted the paper and said, 'Turekian has a *terrible* idea, really a bad idea.' But I guess they don't even want to think about it."

Turekian is studying sulfate in connection with 'acid rain.' He has found that fogbound mountaintops receive 2 to 3 times more sulfate than they would from rainfall alone.

On land, the search for a safe way to dispose of radioactive and other toxic wastes may be aided by an important study Turekian and his colleagues are conducting on how ions travel through different groundwater aquifers. If this movement is slow enough, radioactive waste could decay before it gets from a dumpsite to a source of drinking water, for example. The rate of travel for a particular ion depends on the topography of an area as well as the soil type. By the process of adsorption and desorption, an ion bonds to some compound in the soil, washes off, bonds again, and so on through the groundwater. First measuring the natural radioactivity of the groundwater, the group can then predict or measure how fast an added substance moves underground. This rate of travel is called the retardation factor. They have already determined the retardation factors for all types of aquifers in Connecticut.

Turekian's laboratory also is studying the flux of sulfate, one of the ingredients of "acid rain," from air to groundwater. There are many variables, but it now appears that mountaintops which are often shrouded in fog receive two to three times more sulfate than they would from rainfall alone; the trees act as aerosol traps. This could be one reason some lakes end up with more sulfate than others.

The work with groundwater is only part of a worldwide project to measure exchanges between the sea, the air, and the land. With radioactive isotopes, each of which has a different half-life, geochemists can even measure how much dust from a desert ends up in a particular ocean. Turekian also has used the radioactive isotopes trapped in shells to measure the growth rates of clams at geothermal vents on the ocean floor. At one vent, a clam grew a foot long in about six years, he found. At another, a clam of the same species took 27 years to grow to the same size. Perhaps the vents turn on and off. The lab has analyzed the natural radioactive isotopes in water from the vents, to learn about the rate of flow. And Turekian has used isotopes in a study of Mt. St. Helens, to try to learn what part of the earth's mantle certain volcanic rocks come from. "Volcanoes are our eyes into the mantle," he says.

"You should never forfeit your own work," he warns. "If you do, you're a jerk, because that's what really keeps you going."

Though he initiates and oversees many concurrent projects, Turekian leaves much of the lab work to his colleagues and students, whom he feels are more skilled now than he is anyway. As chairman of the university's Department of Geology and Geophysics, his job is to allocate the department's resources wisely. He doesn't seem to mind the extra responsibilities and distractions of the chairmanship, devoting much of his time to grant proposals and promotional work for the department as a whole, but the position keeps him busy enough to start his day very early in the morning. "He doesn't sleep," says Roxanne simply.

Recently he put a great deal of time and energy into choosing two new faculty members, as well as serving on the search committee for a new Dean for the School of Forestry and Environmental Studies; but he says it was worth the trouble because it was an investment in the future. He cares deeply for Yale and its future, and wants to make sure the university stays at the forefront of geology and geophysics. "But you should never forfeit your own work," he warns. "If you do, you're a jerk, because that's what really keeps you going."

His own work is what has made him a pioneer in his field, but there is one trend he is bucking — he doesn't like computers. "I'm too old [55] for computers," he said, walking back to his office against a chilly wind. "The only thing that distinguishes human thought from a computer is that our thought is full of non sequiturs." Only then did I realize that his students get an extra bonus from "Coffee Time." Aside from the scientific insights produced by Turekian's spirited, combative leadership, the session has a tremendously therapeutic value as a sort of scientific encounter group. It is humanizing.

Exclusive Economic Zone

A Proclamation by President Reagan

March 10, 1983

WHEREAS the Government of the United States of America desires to facilitate the wise development and use of the oceans consistent with international law;

WHEREAS international law recognizes that, in a zone beyond its territory and adjacent to its territorial sea, known as the Exclusive Economic Zone, a coastal State may assert certain sovereign rights over natural resources and related jurisdiction; and

WHEREAS the establishment of an Exclusive Economic Zone by the United States will advance the development of ocean resources and promote the protection of the marine environment, while not affecting other lawful uses of the zone, including the freedoms of navigation and overflight, by other States;

NOW, THEREFORE, I, RONALD REAGAN, by the authority vested in me as President by the Constitution and laws of the United States of America, do hereby proclaim the sovereign rights and jurisdiction of the United States of America and confirm also the rights and freedoms of all States within an Exclusive Economic Zone, as described herein.

The Exclusive Economic Zone of the United States is a zone contiguous to the territorial sea, including zones contiguous to the territorial sea of the United States, the Commonwealth of Puerto Rico, the Commonwealth of the Northern Mariana Islands (to the extent consistent with the Covenant and the United Nations Trusteeship Agreement), and United States overseas territories and possessions. The Exclusive Economic Zone extends to a distance 200 nautical miles from the baseline from which the breadth of the territorial sea is measured. In cases where the maritime boundary with a neighboring State remains to be determined, the boundary of the Exclusive Economic Zone shall be determined by the United States and other State concerned in accordance with equitable principles.

Within the Exclusive Economic Zone, the United States has, to the extent permitted by international law, (a) sovereign rights for the purpose of exploring, exploiting, conserving and managing natural resources, both living and non-living, of the seabed and subsoil and the superjacent waters and with regard to other activities for the economic exploitation and exploration of the zone, such as the production of energy from the water, currents and winds; and (b) jurisdiction with regard to the establishment and use of artificial islands, and installations and structures having economic purposes, and the protection and preservation of the marine environment.

This Proclamation does not change existing United States policies concerning the continental shelf, marine mammals and fisheries, including highly migratory species of tuna which are not subject to United States jurisdiction and require international agreements for effective management.

The United States will exercise these sovereign rights and jursidiction in accordance with the rules of international law.

Without prejudice to the sovereign rights and jurisdiction of the United States, the Exclusive Economic Zone remains an area beyond the territory and territorial sea of the United States in which all States enjoy the high seas freedoms of navigation, overflight, the laying of submarine cables and pipelines, and other internationally lawful uses of the sea.

IN WITNESS THEREOF, I have hereunto set my hand this tenth day of March, in the year of our Lord nineteen hundred and eighty-three, and of the Independence of the United States of America the two hundred and seventh.

Ronald Reagan

Ocean Policy Statement By the President

March 10, 1983

The United States has long been a leader in developing customary and conventional law of the sea. Our objectives have consistently been to provide a legal order that will, among other things, facilitate peaceful, international uses of the oceans and provide for equitable and effective management and conservation of marine resources. The United States also recognizes that all nations have an interest in these issues.

Last July I announced that the United States will not sign the United Nations Law of the Sea Convention that was opened for signature on December 10. We have taken this step because several major problems in the Convention's deep seabed mining provisions are contrary to the interests and principles of industrialized nations and would not help attain the aspirations of developing countries.

The United States does not stand alone in those concerns. Some important allies and friends have not signed the Convention. Even some signatory States have raised concerns about these problems.

However, the Convention also contains provisions with respect to traditional uses of the oceans which generally confirm existing maritime law and practice and fairly balance the interests of all States.

Today I am announcing three decisions to promote and protect the oceans interests of the United States in a manner consistent with those fair and balanced results in the Convention and international law.

First, the United States is prepared to accept and act in accordance with the balance of interests relating to traditional uses of the oceans — such as navigation and overflight. In this respect, the United States will recognize the rights of other States in the waters off their coasts, as reflected in the Convention, so long as the rights and freedoms of the United States and others under international law are recognized by such coastal States.

Second, the United States will exercise and assert its navigation and overflight rights and freedoms on a worldwide basis in a manner that is consistent with the balance of interests reflected in the Convention. The United States will not, however, acquiesce in unilateral acts of other States designed to restrict the rights and freedoms of the international community in navigation and overflight and other related high seas uses.

Third, I am proclaiming today an Exclusive Economic Zone in which the United States will exercise sovereign rights in living and non-living resources within 200 nautical miles of its coast. This will provide United States jurisdiction for mineral resources out to 200 nautical miles that are not on the continental shelf. Recently discovered deposits there could be an important future source of strategic minerals.

Within this Zone all nations will continue to enjoy the high seas rights and freedoms that are not resource-related, including the freedoms of navigation and overflight. My Proclamation does not change existing United States policies concerning the continental shelf, marine mammals and fisheries, including highly migratory species of tuna which are not subject to United States jurisdiction. The United States will continue efforts to achieve international agreements for the effective management of these species. The Proclamation also reinforces this government's policy of promoting the United States fishing industry.

While international law provides for a right of jurisdiction over marine scientific research within such a zone, the Proclamation does not assert this right. I have elected not to do so because of the United States interest in encouraging marine scientific research and avoiding any unnecessary burdens. The United States will nevertheless recognize the right of other coastal States to exercise jurisdiction over marine scientific research within 200 nautical miles of their coasts, if that jurisdiction is exercised reasonably in a manner consistent with international law.

The Exclusive Economic Zone established today will also enable the United States to take limited additional steps to protect the marine environment. In this connection, the United States will continue to work through the International Maritime Organization and other appropriate international organizations to develop uniform international measures for the protection of the marine environment while imposing no unreasonable burdens on commercial shipping.

The policy decisions I am announcing today will not affect the application of existing United States law concerning the high seas or existing authorities of any United States government agency.

In addition to the above policy steps, the United States will continue to work with other countries to develop a regime, free of unnecessary political and economic restraints, for mining deep seabed minerals beyond national jurisdiction. Deep seabed mining remains a lawful exercise of the freedom of the high seas open to all nations. The United States will continue to allow its firms to explore for and, when the market permits, exploit these resources.

The Administration looks forward to working with the Congress on legislation to implement these new policies.

Comments on the Statement

As with the Truman Proclamation of 1945, which declared United States economic jurisdiction over the continental shelf out to a depth of 200 meters, President Reagan's Proclamation on the 200-mile Exclusive Economic Zone (EEZ) was accompanied by an official statement. While the Proclamation itself is short and does not elaborate on its provisions, the President's statement is more detailed and helpful in understanding the policy implications of the Proclamation.

Reagan's statement clearly indicates that the Administration believes there are many provisions in the Law of the Sea (LOS) Convention that are compatible with the interests of the United States. Provisions in Part XI of the Convention dealing with deep seabed mining, however, are explicitly mentioned as problematic and totally unacceptable to the United States. In the absence of a universally binding convention, the President's statement declares that the United States will base its international ocean practices on those aspects of the Law of the Sea that "fairly balance the interests of all States."

Navigation and Overflight

The President's statement outlines three ways in which the United States will continue to promote and protect its ocean interests consistent with "those fair and balanced results in the [LOS] Convention and international law." The first of these concerns traditional coastal uses of the oceans such as navigation and overflight. The United States will recognize the rights of other nations in waters off their coasts, "so long as the rights and freedoms of the United States and others under international law are recognized by such coastal States."

The second component of the President's efforts to promote United States ocean interests addresses navigation and overflight rights and freedoms on a worldwide basis. The President has specified that the United States will exercise its navigation and overflight rights and freedoms worldwide in a manner consistent with provisions of the LOS Convention. He warned that the United States "will not . . . acquiesce in unilateral acts of other States" that restrict the rights and freedoms of the international community in navigation, overflight, and related high seas uses. This part of the statement is designed to show other nations that the United States will exercise its navigation and overflight rights and freedoms in accordance with provisions in the Convention. Thus, without being a party to that Convention, the President is further adapting its acceptable provisions into national policy.

Reagan's warning in regard to "unilateral acts of other States" is clearly intended to dissuade nations that might consider retaliatory actions against the United States (such as denying U.S. navigation and overflight as provided in the Law of the Sea), for our not participating in the Convention. Of course, such an approach might anger certain nations that seek to pressure the United

States into signing and ratifying the LOS Convention. Retaliatory action (especially toward marine science) is a possibility from nations traditionally hostile to the United States. It is doubtful, however, that coastal nations with more cordial or necessary diplomatic, economic, and military ties to the United States will retaliate significantly.

The EEZ

The third part of Reagan's plan is the new 200-mile Exclusive Economic Zone (EEZ). The Proclamation ensures that U.S. policies over fisheries, marine mammals, highly migratory species of tuna, and the continental shelf will not materially change. Under provisions of the 1958 Geneva Convention on the Continental Shelf, coastal nations have sovereign rights to explore and exploit natural resources of the continental shelf adjacent to their coasts. According to this Convention, the continental shelf is legally defined as extending to a depth of 200 meters or, beyond that limit, "to where the depth of the superjacent waters admits of the exploitation of the natural resources" of the shelf. If commercially exploitable resources existed within 200 nautical miles but beyond the legal definition of the shelf, legal uncertainties about coastal state jurisdiction over those resources remained a possibility. However, under provisions of the Proclamation, the United States will now be able to fully control resource-related activities on the deep seabed beyond the continental shelf but within 200 nautical miles of the coast. This provision is of interest with regard to the potential commercial exploration and exploitation of polymetallic sulfide ore deposits that are or may be located within the 200-nautical-mile limit but beyond the continental shelf, on the Juan de Fuca ridge areas off the Washington and Oregon coasts (see *Oceanus*, Vol. 25, No. 3, p. 42, and the following article on recent cobalt discoveries). The Gorda ridge, also in the same general area, is within the 200-mile EEZ limit of the United States. As of Spring 1983, there had not been any polymetallic sulfide deposits found on the Gorda ridge. The Commerce and Interior departments believe that with additional exploration activity, sulfide deposits may be located on that ridge.

The Proclamation establishes sovereign rights for other economic activities associated with the exploitation and exploration of the zone for the production of energy from water, currents, and winds. The Reagan Proclamation also establishes that the primary criterion to be used in boundary delimitation between opposite and adjacent states shall be "equitable principles," the same method outlined in the Law of the Sea Treaty.

Scientific Research

The Proclamation does not claim jurisdictional control with regard to marine scientific research in the EEZ; although the LOS Convention does (Article 56, paragraph 1 (b) (ii)). By allowing foreign nations to freely carry out marine scientific research within the United States EEZ, it would appear that the President is hoping to set an example for U.S. marine scientific access to foreign EEZs. According to the President's statement, the United States will recognize the right of other coastal nations to exercise jurisdiction over marine scientific research within their 200-mile EEZs "if that jurisdiction is exercised . . . in a manner consistent with international law."

Lest one get the impression that Reagan is backtracking on his LOS stand, the President's statement declares deep seabed mining as a "lawful exercise of the freedom of the high seas open to all nations," and declares that the United States will continue to explore for and, when market conditions warrant, exploit the mineral resources of the deep oceans. The statement makes clear, however, that "the United States will continue to work with other countries to develop a regime, free of unnecessary political and economic restraints, for mining deep seabed minerals beyond national jurisdiction."

The President's statement concludes by inviting Congress to work together with the Administration to implement the new policies outlined in the Proclamation.

Implications

The Reagan Proclamation effectively asserts resource jurisdiction and control for the United States over an area nearly twice the size of its total land mass. With a 200-mile EEZ, the United States now has the largest ocean resource area (exclusive economic zone) under the national jurisdiction of any country in the world. Prior to the Proclamation, the United States, like many other coastal nations, had established a 200-mile fisheries zone and jurisdiction over the continental shelf.

On September 30, 1982, Congressman John Breaux, Democrat of Louisiana, introduced HR 7225, a bill setting up a 200-mile EEZ. Senator Ted Stevens, Republican of Alaska, introduced a similar bill (S. 2997) in the Senate. The bills died at the end of the 97th Congress. They were not re-introduced early in the 98th Congress because of the expectation of the President's Proclamation. Now that the Proclamation has been issued, Congress can legislate specific components to the EEZ. Within hours of the official release of the Proclamation, Senator Stevens and Representative Breaux (along with 18 co-sponsors) announced the introduction of legislation (S. 750 and HR 2061) to implement the EEZ, but both bills differ somewhat from the Proclamation. As of spring, 1983, S. 750 calls for a five-year phase-out of all foreign fishing in the new EEZ. Such a provision would not be compatible with the LOS Convention. Both differ from the Reagan Proclamation regarding marine scientific research. They do not acknowledge a *de jure* (according to law) right of other coastal nations to regulate marine science in their waters, but admit only to a *de facto* (actual, in practice) right to do so.

Although there has been some, though minimal, opposition (within and outside Congress) against the President's actions, there is little Congress can do to nullify the Proclamation. Because it deals primarily with foreign affairs aspects of ocean resources and control, the Proclamation is constitutionally embedded in the realm of executive power and authority.

Attention will now focus on Congressional legislation that elaborates on agency responsibility and amendments to domestic laws concerned with the provisions of the new 200-mile EEZ. It should be noted that it was eight years before Congress took action that resulted in the 1953 Outer Continental Shelf Lands Act, expressly dealing with continental shelf provisions outlined by the Truman Proclamation of 1945. Given the highly politicized environment associated with the Law of the Sea and the Reagan Proclamation, Congressional action might proceed more quickly today. However, because the bills will require hearings in several committees and subcommittees, and because numerous agency jurisdictions will have to be negotiated, the legislation could be held up.

If adverse reaction from the world community in response to Reagan's EEZ Proclamation is minimal, then Congress is more likely to pass EEZ legislation quickly. It is unlikely, however, that provisions of either bill that directly contradict the LOS Convention will become law in the foreseeable future.

Timing

The timing of the Proclamation indicates that President Reagan is anxious to establish a national ocean framework separate from, yet compatible with the non-seabed portions of the LOS Convention as quickly as possible. The President's ocean policy statement is additional evidence that the Administration intends to design its own direction in ocean law, but will do so in a manner that is consistent whenever possible with the LOS Convention. The next step might be a 12-mile territorial sea. After all, if most coastal states extend their territorial sea limits to that distance (and 105 nations have done so), why not follow up the EEZ Proclamation with an assertion of a 12-mile territorial sea limit for the United States? In accordance with the Proclamation, a basis for doing so would be to facilitate the wise development and use of the ocean consistent with international law. The probable reason the President chose not to extend the territorial sea is that the United States favors a narrow ocean zone of coastal sovereignty, in order to maximize the chances of the Navy's unfettered passage through straits around the world. Under provisions of the LOS Treaty, a country can claim a maximum of a 12-mile territorial sea, but is not obliged to claim that entire distance.

If President Reagan had waited for Congressional action to legislate a 200-mile EEZ, he might have lost the initiative in establishing the beginnings of a legal framework for the oceans separate from the LOS Convention. If the United States finds itself alone in rejecting that treaty, there will be a considerable amount of domestic pressure to sign and ratify it at a later date. It is only as a signatory to the Convention that a nation can hope to directly influence the work of the treaty's Preparatory Commission (PrepCom). President Reagan has decided that the United States will not attend the PrepCom meetings even as an observer. Therefore, the President hopes to establish a viable alternative as an example for other nations to follow, particularly the industrialized nations.

Several western developed nations are awaiting the success or failure of the Preparatory Commission negotiations to determine whether or not they will eventually sign and/or ratify the LOS Convention. Because President Reagan has said the United States would not participate, even as an observer, at the PrepCom talks, there is little to lose in diplomatic terms or negotiating effectiveness by proclaiming a 200-mile EEZ. Other nations might hold off on similar action for fear of undermining their ability to work effectively in the PrepCom process. Although it is doubtful that a significant degree of effectiveness would be lost as the result of unilateral action compatible with the LOS, other analysts might argue differently.

In broad international terms, the Proclamation is an attempt to show the world that the United States still has sufficient diplomatic and economic influence to go it alone if it feels an international treaty (or a portion of one) is not in its national interest. The Proclamation also aligns the United States with the rest of the world in asserting sovereign rights and jurisdiction within an Exclusive Economic Zone, while confirming certain rights and freedoms of all nations within that zone. In domestic terms, the President has created a viable legal framework for the exploitation of resources in, and jurisdictional control over, the 200-mile EEZ.

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Woods Hole, Mass.

Cobalt-Rich Areas Reported Within EEZ

The President's statement refers to "mineral resources out to 200 nautical miles that are not on the continental shelf." He adds that "recently discovered deposits there could be an important future source of strategic minerals." This apparently is a reference in part to a U.S. Geological Survey (USGS) report released in September of 1982 that confirmed the presence of cobalt-rich deposits in the central Pacific near Hawaii and U.S. Trust Territories.

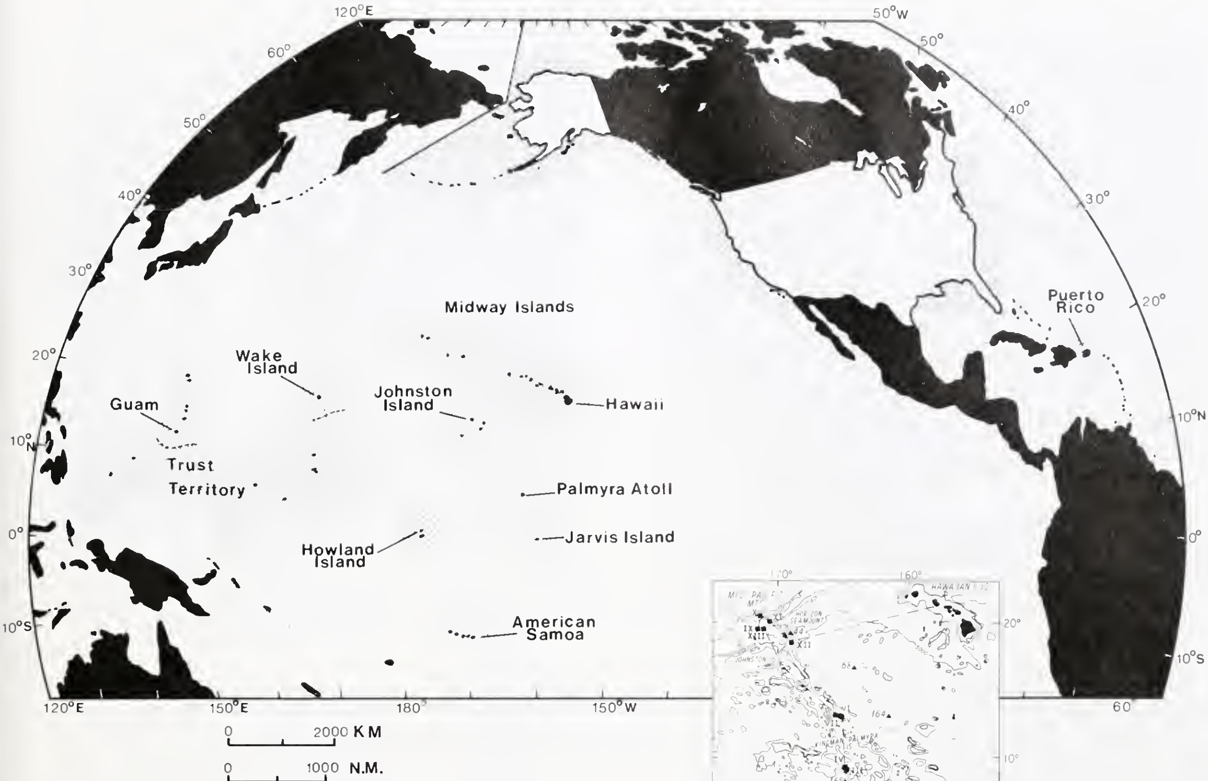
The report was based on a West German expedition in the summer of 1981 and also on followup evaluations partly conducted by USGS scientists. The United States presently depends heavily on the African nations of Zambia and Zaire for imports of cobalt, a vital ingredient in the manufacture of high-temperature superalloys, such as those used in jet engines.

Dredged cobalt-rich manganese crust samples were taken from the broad tops and gentle slopes of seamounts (underwater mountains) in relatively shallow waters (from 2,500 to 1,200 meters deep).

The report, compiled by Peter Halbach, a professor at the Technical University in Clausthal-Zellerfeld, West Germany, and chief scientist of the *R/V Sonne* expedition, and Frank T. Manheim, project chief for Ocean Hard Minerals at the Woods Hole, Massachusetts, office of the USGS, states that at water depths of less than 2,600 meters the crusts contain 1 percent cobalt or more. Where the slope and top of the seamount are older than mid-Tertiary time (about 20 million years ago) "these crusts range up to 9 centimeters in thickness, and average at least 2 centimeters."

The scientists estimated that each seamount in the region covered by the expedition — the sampling was conducted at two locations along the Line Islands Ridge and at several points in the eastern part of the mid-Pacific Mountains (see map) — averaged 300 square kilometers and could yield several million tons of ore.

The report noted that seamount crusts are unlike potato-sized manganese nodules and that a different technology would be needed for their recovery. The area sampled was partially inside and partially outside the new extended U.S. jurisdiction. Studies by researchers at the University of Hawaii, according to the USGS,



Two-hundred nautical mile boundaries of the United States, its Pacific possessions, and the former U.S. Pacific Trust Territories. (USGS map MF 1360, 1981.) Inset shows Mid-Pacific Mountains and Line Islands Ridge areas covered by 1981 West German expedition. (From Halbach and Manheim, in preparation)

have established that slopes around the Hawaiian Islands and Ridge contain crusts with cobalt concentrations approaching those of the mid-Pacific area. Speculatively, islands of the former U.S. Pacific Trust Territories may have similar crust-covered slopes with commercial potential.

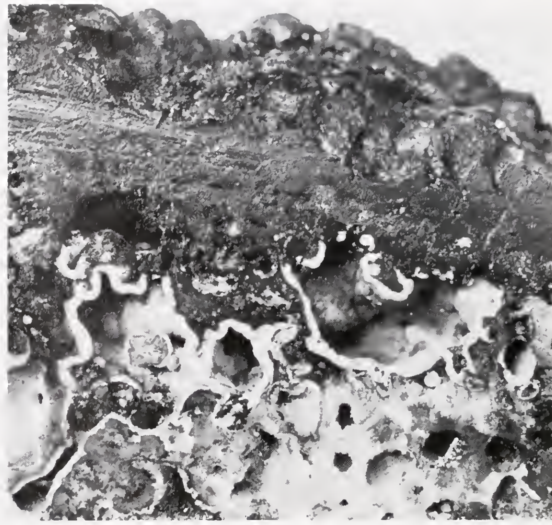
The Pacific Ocean, it seems, is not the only ocean showing enhanced cobalt in crusts. According to a U.S. Bureau of Mines sponsored data file, cobalt values higher than 1 percent have been reported in the Atlantic and Indian (northeast of Madagascar) oceans. And Manheim, in a cruise in September of 1982, reported that hard mineral-rich pavement covered more than 14,000 square kilometers of the Blake Plateau, which stretches offshore from the Carolinas to Florida. Much of the entire plateau, although beyond the continental shelf, is within the extended U.S. jurisdiction of 200 nautical miles.

The findings from the Blake Plateau cruise revised previous estimates of the economic value of the resources in place. Manheim, chief scientist on the cruise, reported that the distribution of manganese nodules on the plateau was less than previously thought, but that the amount of pavement and slab may be greater. Prime Blake nodules contain on the average 16 percent manganese, 10% iron, .6% nickel, .3% cobalt, and .1% copper.

The expedition made use of the Woods Hole Oceanographic Institution's camera sled *Angus* to photograph thousands of areas the size of an average home. The photos revealed "windrows" of manganese cobbles, boulders, and pavement, including slumped plates of manganese-phosphorite pavement the size of garage walls. The expedition also made use of a new Japanese three-frequency acoustic system to measure the concentration of nodules on the ocean floor. In addition, an improved impact coring system was used that recovered hard rock samples from the seafloor.

In 1982, the Interior Department began the process of establishing a program for mineral leasing bids on the Blake Plateau. Reynolds International had earlier requested leases, but it subsequently withdrew its request. An Interior Department

Sample of ferromanganese crust broken free from substrate on Line Islands seamount. (Photo by Frank Manheim)



Close-up view of cobalt-rich crust on phosphatized carbonate ooze from the mid-Pacific seamounts. Thickness of crust is 3 to 4 centimeters. (Photo by Frank Manheim)

source reports that the interest of many commercial firms is now centered on the proposed Minerals Management Service lease program in the Gorda Ridge area off Washington and Oregon, and on the possibility of mining cobalt-rich crusts in the mid-Pacific.

Given the present low price of cobalt, manganese, and nickel on the international metals market, it is unlikely that ocean mining for manganese nodules and cobalt-rich crusts will take place before the end of the century. What is of particular concern and significance to the United States government and mining industry is that if market conditions make cobalt-rich crusts commercially attractive, those deposits may be mineable within the economic jurisdiction of the United States.

Paul R. Ryan

The Law of the Sea Convention

Editor's Note: The following material has been excerpted from a paper prepared for Reagan Administration officials by the White House Office of Policy Information. It outlines the Administration's position with respect to the United Nations Convention on the Law of the Sea. The paper was dated April 15, 1983. We are publishing the material without comment as we believe it is important for our readers to know how the U.S. government is proceeding in this critical area of ocean affairs. We tried to be as judicious as possible in making deletions (for space reasons), taking out only material either already well known or of a highly speculative nature.

On December 10, 1982, signing ceremonies for the United Nations Convention on the Law of the Sea (LOS) were held at Montego Bay, Jamaica. While 117 countries signed the treaty, the United States and 46 other nations, together representing more than half of the world's GNP [Gross National Product], chose not to sign the document.

President Reagan had announced on July 9, 1982, that the United States would not sign. In making this statement, the President acknowledged that the treaty contained "many positive and very significant accomplishments," but noted that "the deep seabed mining part of the convention does not meet U.S. objectives" and was unacceptable.

The Administration's earlier review had identified several draft treaty provisions with regard to deep seabed mining that would be distinctly harmful to U.S. and other countries' interests. Accordingly, the President, on January 29, 1982, made explicit six major U.S. objectives in the LOS Treaty negotiations. An acceptable treaty, he said, must:

1) Not deter development of any seabed mineral resources to meet national and world demands.

2) Assure national access to these resources by current and future qualified entities to enhance U.S. security of supply, to avoid monopolization of the resources by the operating arm of the International Authority, and to promote the economic development of the resources.

3) Provide a decision-making role in the deep seabed regime that fairly reflects and effectively protects the political and economic interests and financial contributions of participating states.

4) Not allow for amendments to come into force without approval of the participating states, including the advice and consent of the U.S. Senate.

5) Not set other undesirable precedents for international organizations.

6) Be likely to receive the advice and consent of the U.S. Senate.

At the President's direction, the U.S. sought certain revisions that would have brought the document more in line with these objectives. Several U.S. allies supported that effort.

However, the Third World nations that dominated the LOS negotiations rejected the proposed revisions, preventing the LOS convention from meeting any of the U.S. objectives.

U.S. Interests at Stake

The ability of the United States and the allied powers to defend themselves and sustain their economies rests on assured access to several strategic minerals. Among the most important are cobalt, manganese, and nickel, without which we cannot manufacture jet engines nor produce steel.

Unfortunately, the United States and many other free world nations, unlike the Soviet Union, are heavily dependent on foreign sources for these and other vital minerals. Many of these sources are unreliable. The chief non-Communist suppliers of manganese and cobalt include countries that suffer from endemic political and economic instability. As has happened in the past, war, a coup, or civil unrest in these countries could interrupt U.S. supplies or terminate them outright.

Moreover, high-grade land-based resources continue to be depleted. The free world's known resources of economically recoverable manganese, for instance, may be exhausted within 30 years or less.

One promising alternative source for the future are minerals on the ocean floor. Vast quantities of manganese, cobalt, and other vital minerals, including nickel and copper, are to be found beneath the high seas in a variety of forms, ranging from pebble-sized polymetallic nodules to the newly discovered sulfide deposits and cobalt/manganese crusts.

Under international law, development of these deep ocean minerals is a freedom of the high seas open to exercise by any nation. The Law of the Sea Treaty would eliminate this free access for all nations, and transfer control of the ocean's minerals to an international authority dominated by Third World states, which are largely hostile to free market approaches and to the interests of the industrialized nations of the free world. Granting them veto power over development of resources that are potentially valuable to western economic and security interests would thus be dangerously short-sighted. It would also be a gross perversion of this country's original goals in the LOS process.

The New Economic Order

The United States and the other developed countries entered into the LOS negotiations primarily to achieve a balanced and mutually beneficial resolution of certain difficult issues related to the use of the world's oceans. Many of the less-developed countries, however, had another object in mind: to use the LOS process as a vehicle for the mandatory transfer of wealth and technology from "have" nations of the globe to the "have nots."

The LOS sessions were dominated from beginning to end by a coalition of these developing states, known as the "Group of 77" (which now number 120). The ultimate aim of the Group of 77 is the establishment of a New International Economic Order (NIEO), a scheme for restructuring the international economy along the socialist lines of the world's centrally-managed economies and for redistributing the world's wealth. The LOS treaty is viewed by the Group of 77 as a significant step toward this end because the seabed provisions enshrine several NIEO principles.

One of the most instrumental of the NIEO's concepts is the treaty's proclamation that the resources of the deep seabed are the "common heritage of mankind." This idea, first propounded in an address to the U.S. General Assembly by Ambassador Arvid Pardo of Malta in 1967, was later incorporated into a resolution by that body in 1970. The U.S. supported that resolution with the provision that it had no intrinsic legal meaning and could acquire substance only through a universally accepted treaty. Short of that, the U.S. view has consistently been that the deep seabed is the exclusive province of no one nation or group of nations, and may therefore be developed by anyone willing to expend the necessary capital and assume the inevitable risks associated with that development.

Yet the dominant Third World viewpoint is just the opposite: that the deep seabed is the collective property of all nations, that an international body — which the Third World countries would effectively control — should regulate access to the seabed, and that any fruits of development should be distributed to all countries, regardless of whoever undertakes the burden of mining.

These ideas, once established in the LOS convention, could easily be applied in other areas. In particular, the LOS treaty would set a precedent for further Third World efforts to dictate the use of resources beyond national jurisdiction, such as control of Antarctica and other unclaimed resource depositories, and, possibly, the International Monetary Fund and World Bank.

Concern over the LOS treaty therefore transcends the issue of the national or private right to mine the ocean floor, although that in itself is certainly important. In broader terms, the question is whether the United States should endorse an agreement that, by its failure to meet stated U.S. objectives, remains contrary to fundamental American political and economic principle interests.

There is a practical side to this question as well. Free-market economies have, almost without exception, generated far higher standards of living for all their peoples than have those rooted in socialist doctrine. Relying on the discredited centralized economic control techniques of the latter as the basis for mining the minerals of the seabed would therefore be one of the least effective means possible for promoting global prosperity.

Other Treaty Flaws

There remain other serious flaws in the LOS treaty. The treaty, for example, could subsidize international terrorism. Several "national liberation groups," including the Palestine Liberation Organization (PLO) and the South-West Africa People's Organization (SWAPO), had observer status at LOS negotiations. Under the terms of the treaty, these and other similar groups could share in the distribution of seabed wealth.

Another serious objection to the treaty is that it could be amended after 20 years by a three-fourths vote and ratification by nations party to the treaty. Thus, if it ratified the treaty, the U.S. would for all practical purposes lock itself into any such changes, having little choice other than withdrawing from the treaty. Even U.S. Senate rejection of the treaty amendments would not necessarily prevent them from going into effect. The Group of 77 and its allies would comprise at least three-fourths of most conceivable sets of treaty signatories, and would effectively control the amendment process.

Alternatives to LOS Treaty

Ratification procedures provide that 60 nations must approve the treaty for it to go into effect. At this time, it remains to be seen how many states will ratify the LOS convention. For while representatives of more than 117 nations have signed the document, this does not mean that ratification is a foregone conclusion. The U.S. and some other key industrialized countries have not signed it. Under the circumstances, many of the countries whose delegates signed the LOS treaty may defer ratification until they see what the developed nations intend to do.

Fortunately, there are attractive and beneficial alternatives to the seabed mining provisions of the LOS treaty. Some developed nations might well opt for this type of arrangement. Indeed, individual sovereign states possess the requisite authority to authorize and regulate the ocean mining activities of their citizens, and to enter into reciprocal agreements with one another — including mutual recognition of mining operations conducted by their citizens.

Conclusion

The Law of the Sea Treaty's seabed mining regime is thus hopelessly flawed. It will not produce a positive consensus that would enrich international law, nor contribute to economic development that can benefit all peoples. It also violates some of the United States' fundamental principles, and would exacerbate rather than reduce global tensions.

President Reagan has said that where the mineral wealth of the ocean floor is concerned, the aim of the United States is "to establish with other nations an order that would allow exploration and development under reasonable terms and conditions."

U.S. efforts are now directed toward developing an alternative agreement, based on customary law, that will permit seabed mining and preserve freedom of the seas for all nations. This will be a top priority of the United States in the years ahead.

letters

To the Editor:

Diane Ging — the Phyllis Schlafly of The Deep?

Her objection (Spring issue) to "Women in Oceanography" is classic, even to her threat to "un-subscribe" to *Oceanus*.

Now that she has shaken her curls and stamped her pretty foot, I trust *Oceanus* will roll over and promise never again to imply that the oceans may have any social significance. Let alone political importance!

Elaine McPherson
Grass Valley, Calif.

To the Editor:

I read D. C. Ging's letter deploring your inclusion of the article "Women in Oceanography." May I for one, as a male reader, support your efforts to illuminate this aspect of our field.

Ms. Ging might remark on my personal observation, as a graduate student, that women at the Dalhousie Institute of Oceanography in 1964 more or less equaled men in numbers as graduate students and I am sure equaled us in competence and intelligence. But I am not sure the same can be said for the numbers of women 20 years into our various careers. Something called bias has almost certainly edited the crop down, or was it only the individual's personal expectations of themselves?

Ms. Ging might reflect upon S. A. Foster and A. Berti, in my geology class at the University of Toronto in the early 60s. Both went to all the summer job interviews. A. Berti always got a good field job that was well-paying and which gave good career experience. Ms. S. A. Foster never got a field job as I recall.

I am sure times have changed. But at times it is slow. It behooves us all to take our pulse occasionally and I am pleased *Oceanus* looked in the mirror.

Alan Ruffman, President
Geomarine Associates, Ltd.
Halifax, Nova Scotia

book reviews

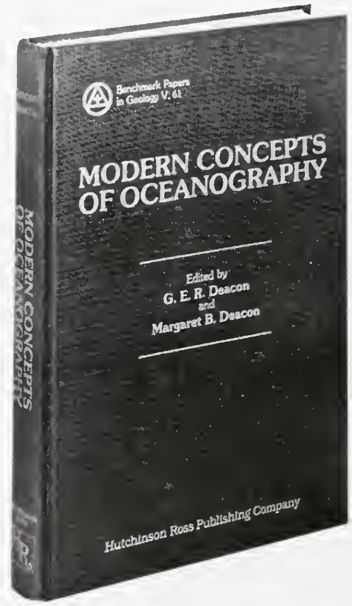
Modern Concepts of Oceanography, G. E. R. Deacon and Margaret B. Deacon, eds. 1982. Hutchinson Ross Publishing Company, Stroudsburg, Pa. 386 pp. $46.00.

In 1978, Margaret Deacon published her first edited collection, *Oceanography: Concepts and History.* It contained 39 papers, stretching from the fascinating "Directions for Sea-men, Bound for Far Voyages," written in 1666, to a pair of 1967 articles on tidal analysis and wind waves. The scope was broad, the choice of papers good, and there was a feeling of excitement in the book. Only three or four of the papers could be called readily accessible today, so the collection had immense value, if only as a way of presenting the fascinating development of oceanography.

A quirk of the book was that the Italian and German papers all appeared in English, but not all the French papers were translated. Since my Italian is better than my French, my personal preferences and abilities interject themselves into my appreciation of the book. This is precisely the point about such collections of "benchmark papers": it is inevitable that the personal preferences of the editors and readers will enter into the selection and appreciation of the collection. There is no objective standard by which to choose and judge. Margaret Deacon is *the* historian of oceanography, and her selection was as good as one could expect.

The second collection, *Modern Concepts of Oceanography,* is edited by Margaret Deacon and her father, G. E. R. Deacon. It ". . . gathers together the wide selection of papers that significantly contributed to the rapid expansion of oceanography after World War II." In fact, the book's 41 papers run the gamut from the 1911 Brennecke work on the German Antarctic Expedition to the 1976 Foster and Carmack study of Antarctic bottom water formation in the Weddell Sea.

Because of the explosion of oceanographic work since World War II, it is clearly of value to stand back and collect the major papers. The difficulty, again, is in the selection. Another attempt to look at



progress since World War II (why must we continue to use WW II as a time mark?) is the Stommel volume, *Evolution of Physical Oceanography* (edited by Bruce Warren and Carl Wunsch, MIT Press, Cambridge, Massachusetts, 1981), which contains 18 major review articles that in turn reference almost 2,000 papers. Surely the 41 papers in *Modern Concepts* are referenced in the Stommel volume? Surprisingly, only 10 are.

A different measure for the selection of papers would be their lack of availability: why bother reprinting recent papers from the *Journal of Geophysical Research,* for example, especially since it is the most widely circulated journal of its kind in the world? Looking at it this way, only about half of the papers in *Modern Concepts* are helpful, since the rest are from standard journals published during the last 20 or 30 years. Perhaps the editors could have simply listed and introduced those easily found papers and used their precious reprint space for the obscure, or for translations.

The most important aspect of paper selection in a "benchmark" collection ought, perhaps, to be the status of each paper as a recognized classic. This is where the present book fails, because the papers tend to *review* or *explain* the classics rather than to *be* the classics. For the technical researcher, this is bad news. The good news is that one gains perspective from such reviews, and insights from the nontechnical explanations, and one tends to browse in the material rather than homing in on the single classic of most interest.

I have scanned the book several times and lingered in the preface, and I have arrived at an appreciation of the selected papers as being of mixed value. Some are wonderful for the student (that is, anyone who is not a researcher on that topic), some are true classics, and some are perhaps both (for example, Langmuir's original paper on the surface circulations that now bear his name). If the editors intended this book to be the definitive collection of papers on modern oceanography, it is a flop. As a group of papers on some aspects of physical oceanography, plus Antarctic biology, it is an interesting and readable volume.

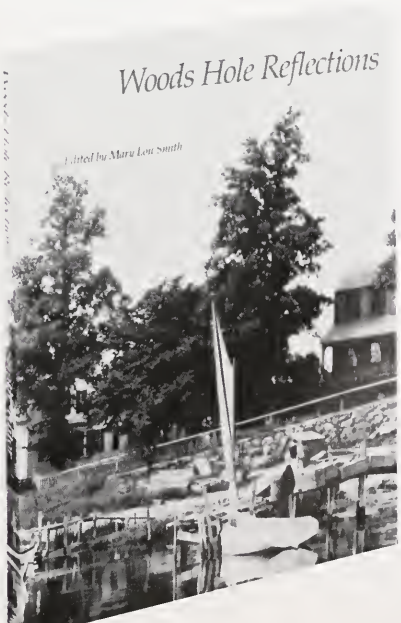
If I had to recommend just four volumes to sit on the bookshelf of a student or worker in physical oceanography, four volumes that provide general information, context, and lists of source material, I would recommend *The Oceans*, by Sverdrup, Johnson, and Fleming, the Stommel volume, and the two collections by Deacon and by Deacon and Deacon. I would suggest that the introductory material in the Deacon books not be ignored. And I would be pleased to see other notable oceanographers take up the challenge, as Sir George and his daughter Margaret have, to try to summarize past events and provide the wisdom and experience they have in their own areas of interest.

Melbourne G. Briscoe,
Associate Scientist,
Physical Oceanography Department,
Woods Hole Oceanographic Institution

***Woods Hole Reflections,* Mary Lou Smith, ed. 1983. The Woods Hole Historical Collection, Woods Hole, Mass. 301 pp. $22.95 hardcover; $15.95 paperback.**

Woods Hole Reflections is a gem of a book. Its multifaceted surface casts illuminating prisms of light from the heart of this unique little village perched on the triceps of Cape Cod.

There is probably no other village that has attracted the likes of Gertrude Stein, Pete Seeger, Buckminster Fuller, and more than 30 Nobel Prize laureates. *Reflections* captures the diverse flavor of Woods Hole with a series of chronological passages that gives equal time to Bruce Warren's insider's view of Woods Hole bars and to Lewis Thomas' elegant essay on the Marine Biological Laboratory. Through words and photographs, the book presents a vivid picture of village life throughout the history of the United States. In the process, it provides a concise history of America's commitment to fisheries research, biomedical studies, and oceanography.



From the beginning, Woods Hole's geography was fated to give it a special place in history. Boston businessmen were quick to discern the advantages of a deep-water port. They established shipbuilding concerns, whaling fleets, a spermaceti candle factory, and a guano fertilizer company of questionable finances. When the legacy of the latter caused the demise of the former, Woods Hole became a habitable summer haven.

Donald Zinn describes the coming of the railroad, which allowed the rich and powerful to shuttle in from Boston and New York until the once quiet village rivaled such summer resorts as Newport and Bar Harbor. It was already a worldly place when Prohibition was passed. Rum runners and coast guardsmen lived side by side, sometimes in the same house.

Margaret Bowles describes the sinking of the local rum-running boat, *Black Duck,* which had national repercussions. Three local men, all well liked in the community, were killed in the incident. It drove home the point that undue force was necessary to uphold the unworkable and unpopular social experiment, Prohibition. All that remains is the Black Duck, a fine restaurant on Water Street. This rich history is told in loving detail by Woods Hole inhabitants past and present.

But there is something else going on in Woods Hole, and that is science. One senses that without science Woods Hole would be just another stuffy Victorian summer resort; with it, the village surges with vitality. The infectious enthusiasm of hundreds of finely tuned minds helps form the unique texture of the community.

In a charming essay, Carleton Winslow details the subtle social lines drawn between the "summer people" of bankers row, the "bug hunters" of the scientific community, and the year-round locals. Despite the distinctions, one senses a tremendous pride of community. People write about their village the way they might write about a lovable old eccentric aunt; born of Victorian ancestry but buoyed by a modern purpose.

Throughout the vagaries of history and the ebb and flow of funding, Woods Hole endures. Part New England fishing village, part wealthy summer resort, and part high-powered science community, the village maintains a unique identity which has been captured in this handsome book.

Bill Sargent, author,
Woods Hole, Mass.

***Tracers in the Sea* by Wallace Smith Broecker and Tsung-Hung Peng. 1982. Lamont-Doherty Geological Observatory, Palisades, N.Y. 690 pp. $35.00.**

Originally intended as an update to an earlier book (*Chemical Oceanography*) by Wallace Broecker, this volume, like the field it covers, has grown beyond earlier expectations. The title is a little too explicit; it belies the breadth and scope of the book. The authors dwell on the inner workings of oceanic geochemistry, ranging from air-sea exchange through to sedimentation processes. The emphasis is on the concepts and mechanisms involved, and the goal is to impart an intuitive understanding of what is "really going on." The style is highly personalized and strongly reflects the viewpoints and scientific approaches of the authors. There is an interesting historical slant, a narrative approach to the development of ideas and discoveries. This leads to a lively and highly readable excursion through the state of the art in marine geochemistry.

The book consists of 10 chapters that focus on the mechanisms and processes of marine systems and contain a generous admixture of real data,

largely gleaned from the GEOSECS expeditions of the 1970s. Each chapter also contains, at the end, a useful summary paragraph, a complement of about six problems, and what the author terms one "superproblem." The problems are not particularly demanding of mathematical or thermodynamical skills, but they are well designed to reinforce a student's conceptual grasp of the subject material. The superproblems present somewhat more of a challenge, and encourage the development of rudimentary "box-model" calculations by the student. These superproblems also are highly anecdotal, and contain such interesting and colorful characters as Spencer Crane, Johannes Theft, and Greg Hormone — names which have a strangely familiar ring to them. On the whole, the problem sections are quite useful in cementing the ideas discussed in the chapters. At the very end of almost every chapter is a "Last Minute Addition," containing a few sentences about very recent work.

The first few chapters discuss marine processes more or less by regions. The first chapter is concerned with the biological mediation of major-element distributions, and the feedback between those properties and biological activity. Chapter 2 concentrates on sedimentation processes and controls, primarily those involving calcium carbonate, but tacking on manganese nodules and opaline sediments. Air-sea gas exchange and its influence are the topics of Chapter 3, where a fair amount of detail is given to the stagnant film model of gas exchange. This chapter also contains a fairly complete discussion of apparent oxygen utilization and the distributions of nitrous oxide and helium isotopes in the ocean. There is a strong emphasis on the CO_2 system here. Chapter 4 continues with a discussion of the uranium-series radionuclides, how they yield information on particle adsorption and the residence times of metals in the ocean. The sixth chapter deals with the checks and balances associated with the major constituents of seawater.

Physico-chemical transport and how it is studied is the topic of the middle of the text. Chapter 5 discusses the various natural nuclide dating techniques, while Chapter 8 concentrates on the transient (anthropogenic) tracers. Advection-diffusion models and the general circulation are the topic of Chapter 7, and the concept of ventilation is discussed. It is in this chapter where many of the authors' views show through, although some attempt at impartiality was made. The final two chapters of the book involve an interesting digression into paleo-oceanography (Chapter 9) and a discussion of the fossil-fuel CO_2 problem.

The reference section at the end of the book has an interesting and potentially useful architecture. It is organized according to topic and is structured in a logical way into three levels. The references are annotated with a few sentences describing the scope and relevance of the work.

Overall, the book is a well-thought-out, highly readable, and often entertaining introduction to modern chemical oceanography. It is not particularly rigorous or mathematical, but it effectively carries across the essence and concepts of marine systems.

As such, it would make an excellent entry-level textbook to oceanography and, as a companion to the more formal texts, would provide a powerful introduction to the field. I would also recommend it highly to oceanographers not of the chemical persuasion, as it provides a reasonably understandable and palatable survey of chemical oceanography as it exists today.

William J. Jenkins,
Associate Scientist,
Chemistry Department,
Woods Hole Oceanographic Institution

Books Received

Aquaculture

Aquaculture Economics Research in Asia: Proceedings of a Workshop Held in Singapore, 2-5 June 1981. **1982. International Development Research Centre: Ottawa, Ontario, Canada. Unipub, New York, N.Y. 128 pp. $15.00.**

An effort toward multidisciplinary analysis of aquaculture systems, this book tries to help producers and consumers by bringing economic analysis together with new technology. Three areas are discussed: existing aquaculture, experimental aquaculture technology, and social welfare/economic considerations for aquaculture development. Finally, there is a summary of the conclusions and recommendations that were reached at the workshop.

Textbook of Fish Health **by George W. Post. 1983. TFH Publications, Inc., Neptune, N.J. 256 pp. $29.95.**

Fishes are subject to a wide variety of diseases, and the study or cure of these requires a different approach than with land animals—after all, fish live in a different medium and have a variable body temperature. Though wild fish populations do occasionally suffer diseases, most modern-day wild fish losses are the result of environmental alteration by man. In fish culture facilities, however, overcrowded conditions lead to rapid movement of pathogens. In this book, diagnosis and control of fish diseases are discussed. There are chapters on bacterial, mycotic, viral, and parasitic diseases in fish; immune response; nutrition; neoplastic diseases; and diseases caused by toxic substances and organic wastes.

Biology

Survival Strategies of the Algae, **Greta A. Fryxell, ed. 1983. Cambridge University Press, New York, N.Y. 144 pp. $32.50.**

For algae, survival in times of hardship means the production of resting spores, an evolutionary advantage that allows many algae to withstand periods of unfavorable environmental conditions. The papers in this book are from a symposium of the same name held in Vancouver, British Columbia, July 15, 1980. They point out what has been accomplished in the study of algal survival strategies and suggest research directions.

The Biology of Marine Plants **by M. J. Dring. 1982. Edward Arnold, Baltimore, Md. 199 pp. $18.95.**

In this book, the author discusses marine plant physiology alone—not merely as a part of marine biology, nor as particular groups of algae. Also covered are the environmental conditions required for plant growth in the sea, ecology, zonation, and other topics. Seaweeds are discussed together with algae, and traditional taxonomy and morphology are bypassed. A basic knowledge of plant biology is assumed, though some background material is provided.

Gulls: An Ecological History **by Frank Graham, Jr.; photographs by Christopher Ayers. 1982. Van Nostrand Reinhold Co., New York, N.Y. 179 pp. + vi. $8.95.**

The author begins by saying: "This is a book about gulls and man, not primarily a natural history of gulls, but, rather, a social history—a record of the relations between man and several of the world's 44 gull species." Because of man's activities (particularly the creation of huge open garbage dumps), gull populations have exploded and their ranges have extended. Gulls have become carriers of contaminants and destroyers of tern and puffin colonies. Now, through drastic measures, man is trying to reduce the number of gulls. The author is a field editor for *Audubon* magazine.

Australia's Great Barrier Reef **by Robert Endean. 1982. University of Queensland Press, St. Lucia, London, and New York, N.Y. 348 pp. + xx. $29.95.**

A beautifully produced, large-format book written for a general audience. The Great Barrier Reef is the single largest assemblage of coral reefs in the world. The basis of the book is classical biology, covering most groups of animals and plants (by family) that live on the reef, and the major ecological problems there. There are separate chapters on hard corals, worms, crustaceans, echinoderms, and coral-reef fishes. The reader, with the help of more than 250 color photographs, will be able to identify most organisms encountered on the Great Barrier Reef.

Chemistry

Chemistry and Biochemistry of Marine Food Products, **Roy E. Martin, George J. Flick, Cheiko E. Hebard, and Donn R. Ward, eds. 1982. AVI Publishing Co., Westport, Conn. 474 pp. + xvii. $45.00.**

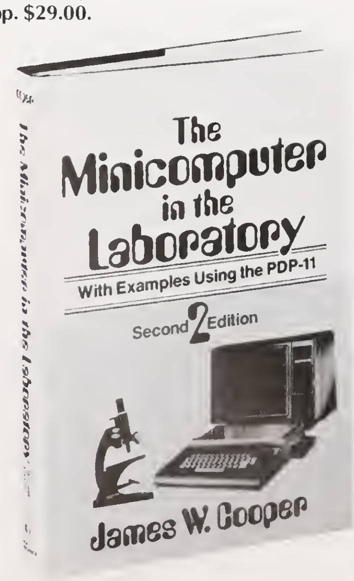
This book is an expansion of a symposium held in 1979 during the meeting of the American Chemical Society. There are many contributors. By bringing together the known facts of the chemistry and biochemistry of marine food products, the editors hope to emphasize the importance of these sciences to fisheries technology. There are 23 chapters, covering topics such as Unusual Properties of Connective Tissue of Cod, Vitamins and Minerals in Seafoods of the Pacific Northwest, and Preservation of Seafood with Modified Atmospheres.

Education

***Finding Your Way on Land or Sea Reading Nature's Maps* by Harold Gatty. 1983. The Stephen Greene Press, Lexington, Mass. 271 pp. $8.95.**

Early humans traveled everywhere without maps, compasses, or scientific gadgets. Pathfinding is a matter of knowledge, combined with observation and deduction; with this book, written by an experienced navigator, one can gain the knowledge and learn the skills needed to keep from getting lost. The pages are filled with information and lore: why we walk in circles and how not to; how to sharpen our senses; natural clues to time, location, and direction. Even anthills can be used as signposts!

***The Minicomputer in the Laboratory, with Examples Using the PDP-11* by James W. Cooper. 1983. 2nd edition. John Wiley & Sons, New York, N.Y. 381 pp. $29.00.**



The minicomputer is widely used as a teaching and research tool (the author uses one in his course on laboratory computing for chemists at Tufts University in Medford, Massachusetts), but few scientists have assembly-language experience. In this updated book, after introductions to the basics of computers and mathematical concepts used, the reader will learn an assembly language and the various types of algorithms useful in the laboratory. There are 21 chapters and six appendices, including the decimal-octal conversion table.

***Science Deified and Science Defied: The Historical Significance of Science in Western Culture, From the Bronze Age to the Beginnings of the Modern Era ca. 3500 B.C. to ca. A.D. 1640* by Richard Olson. 1982. University of California Press, Berkeley, Calif. 329 pp. + xv. $32.50 (hardcover); $9.95 (paperback).**

Scientific modes of analysis practiced by technical experts are increasingly important factors in political and economic decisions. In this book, the author traces the roles of scientific tradition in the development of Western culture, and explores the connections to liberal studies, such as religion, philosophy, and the arts. Beginning with ancient Mesopotamia, the discussion spans the ages, through Pre-Socratic thought, Christianity, and the Renaissance to the time of Sir Francis Bacon.

Environment

***Technologies for Coastal Erosion Control,* Department of International Economic and Social Affairs, Ocean Economics and Technology Branch. 1982. United Nations, New York, N.Y. 132 pp. $14.00.**

Coastal erosion is an important problem throughout the world, with sometimes severe consequences. Controlling erosion is important. In this review, Part One discusses the causes of coastal erosion, differentiating natural from man-made, and the methods used for identifying eroding shorelines. Part Two gives detailed descriptions of the technologies available for controlling erosion. Part Three discusses applicability and evaluates the control mechanisms' labor, capital, and other requirements. Lastly, the institutions dealing with erosion-control technologies are listed.

***North Sea Dynamics,* J. Sündermann and W. Lenz, eds. 1983. Springer-Verlag, New York, N.Y. 693 pp. + xvi. $41.00.**

The proceedings of a symposium, held in the summer of 1981, in Hamburg, West Germany. Forty-five of the 58 lectures presented are printed in this volume. The symposium brought together active researchers in the field of North Sea dynamics, to discuss research problems and future trends. Following a review of the history of international North Sea research, the papers fall into four categories: Currents and Water Balance; Wind Waves and Storm Surges; Transport of Momentum, Energy, and Matter; and Ecosystems.

***The Arctic Ocean: The Hydrographic Environment and the Fate of Pollutants,* Louis Rey, ed. 1982. John Wiley & Sons, New York, N.Y. 433 pp. $89.95.**

The papers in this volume were researched as part of a series organized by the *Comite Arctique International.* The *Comite* aims to improve knowledge of Arctic areas and thus to promote research in different fields on an international, multidisciplinary basis. In five sections, the book covers many areas of Arctic study, beginning with a treatise on the genesis and evolution of the Arctic basin and its discovery by man. Other topics are: Hydrography; Water, Ice, and Atmospheric Interactions; Climatic and Atmospheric Transport; Arctic Biology and Pollution; and Oils and Chemicals in the Arctic Environment.

***Processes in Marine Remote Sensing,* F. John Vernberg and Ferdinand P. Diemer, eds. 1982. University of South Carolina Press, Columbia, S.C. 545 pp. + xiv. $34.95.**

There are 29 papers and four "Group Reports" in this book. Remote sensing is a tool that may be very useful in studying the seas, in their enormity and complex behavior. To pursue this idea, scientists and engineers from the United States and Europe congregated at the University of Manchester, England, in June of 1979. The major topics of discussion incorporated into this book were:

physical targets, transmission medium, signals and information, sensors and instrument systems applications, environmental studies, and observational studies and processing.

The Environment of the Deep Sea, **Rubey Volume II, W. G. Ernst and J. G. Morin, eds. 1982. Prentice-Hall, Inc., Englewood Cliffs, N.J. 371 pp. + x. $38.95.**

The results of a colloquium that took place in the spring of 1979, this book is divided into two interrelated parts. The first deals with the physical and chemical environment of the deep sea; the second, biological aspects. Specific areas of discussion are paleooceanography; chemistry of biogenic matter of the deep ocean floor; bacterial ecology of the deep sea; and the origin, age, and evolution of Antarctic and deep ocean faunas.

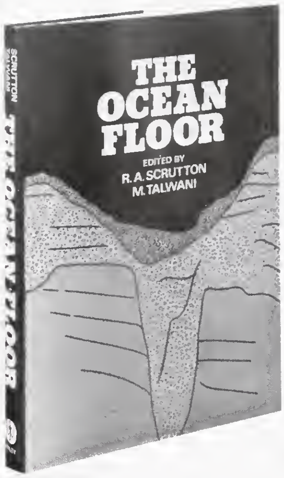
Turbidity in the Aquatic Environment: An Environmental Factor in Fresh and Oceanic Waters **by Charles G. Wilber. 1983. Charles C. Thomas, Publisher, Springfield, Ill. 133 pp. $18.75.**

In water, particles of suspended matter cause light to be scattered and absorbed rather than transmitted in straight lines. This turbidity can reveal information about water quality and origin, changes that occur, and ecological effects. Remote sensing from space now makes it possible to study the turbidity of large bodies of water in some detail, but most books on oceanography and limnology devote little space to the subject. This book sums up all the information on turbidity, including its effects, methods of measurement, and properties in estuaries.

Geology

The Ocean Floor, **R. A. Scrutton and M. Talwani, eds. 1982. John Wiley & Sons, New York, N.Y. 318 pp. + ix. $106.00.**

The papers in this book are dedicated to the memory of Bruce Heezen, a distinguished oceanographer. They have been written by his students, colleagues, and mentors. The collection is meant to reflect Heezen's wide-ranging interests, and thus includes papers on ocean-floor mapping, direct seafloor



observation, sediment geochemistry, continental margins and deep ocean floors, global tectonics and geomagnetic reversals, and many others.

Geology of Offshore Ireland and West Britain **by D. Naylor and P. Shannon. 1982. Graham & Trotman, Ltd., London, England. 174 pp. $53.00.**

In the past decade, the hydrocarbon potential of the offshore areas west of Britain and Ireland has provoked increasing interest. In this book, each sedimentary basin is described in terms of this potential. Also discussed are the paleogeographic potential of the region as a whole and the history of oil and gas exploration. Two appendices supply introductory material to help nonspecialists follow the text and figures.

Marine Policy

The Ocean Dumping Quandary: Waste Disposal in the New York Bight **by Donald F. Squires. 1983. State University of New York Press, Albany, N.Y. 226 pp. $39.50 (hardcover); $10.95 (paperback).**

More than 18 million people live around the New York Bight, and, as author Squires puts it, "shortsightedness is our problem." In this book, the Bight is defined and described, and its population and industrial growth chronicled. One chapter discusses the government's attempts to deal with increasing pollution. Ocean dumping is explored: what is dumped and what it costs. Lastly, Squires addresses some questions concerning the Bight's future.

Ocean and Coastal Law **by Richard C. Hildreth and Ralph W. Johnson. 1983. Prentice-Hall, Inc., Englewood Cliffs, N.J. 514 pp. + xxix. $38.95.**

There are three geographical areas discussed in this book: uplands affected by the sea; coastal waters and the seabed underlying the territorial sea; and offshore waters and resources outside the territorial sea but still under national jurisdiction. The book is further organized to follow the growth of public awareness of coastal problems and the laws that developed to deal with those problems.

Physical Oceanography

The Tides of the Planet Earth **by Paul Melchior. 2nd Edition. 1983. Pergamon Press, New York, N.Y. 641 pp. $90.00.**

Since the first (1978) edition of this book, there has been considerable progress in tidal research. The chapter on observational results is entirely rewritten, and the latest methods for tidal research are discussed. The first chapter includes explanations of tidal force, numerical estimation, and astronomical developments. Another chapter is on the theories of Kelvin and Herglotz regarding earth tides. Another covers liquid-core dynamic theory. There are 17 chapters in all.

General Reading

Tales of Whales **by Tim Dietz. 1982. Guy Gannett Publishing Co., Portland, Me. 130 pp. $7.95.**

Fascinated since boyhood with the sea and its inhabitants, especially whales, Dietz studied whatever he could find on their biology, the whaling industry, and conservation efforts to save whales. But he could never find a book recounting unusual or fantastic encounters with whales. So he wrote one, putting together exciting tales gathered from many sources; some of the stories have yet to be explained. Illustrated with drawings and photographs throughout, the book begins with a synopsis of whale biology and ecology and some guidelines for recognizing whales at sea.

***Waterwomen* by Lila Line. 1982. The Queen Anne Press, Queenstown, Md. 76 pp. $6.95.**

This book, in words and photographs, sketches the lives of five Chesapeake waterwomen. Many works have been written about the Chesapeake Bay, its history, and the watermen who make their livings there, but little has been said about the women who do the same. Readers may be surprised to find that there is a small but resolute group of waterwomen, crabbing, clamming, oystering, and fishing. Why do they do it? For the same reason given by their male counterparts: independence.

***Islands of Maine: Where America Really Began* by Bill Caldwell. 1981. Guy Gannett Publishing Co., Portland, Me. 253 pp. $12.95.**

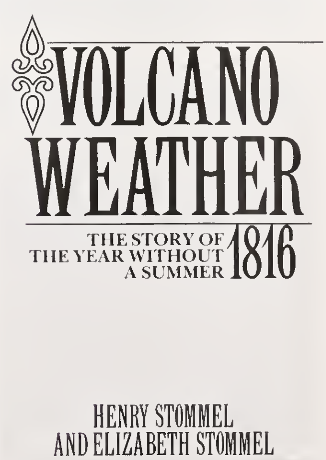
Written by someone who obviously knows and loves the area, this book is a historical account of the islands, and the people inhabiting them, off the coast of Maine. Long before the Pilgrims reached Plymouth Rock, English fishermen had established camps on the Maine islands where they dried cod in the sun. Nowadays, visitors to Maine admire its seacoast beauty; in this book one can learn of the detailed, interesting, and surprising history of the area.

***Dolphin Dolphin* by Wade Doak. 1981. Sheridan House, White Plains, N.Y. 245 pp. $32.50.**

Wade and Jan Doak, longtime divers and sailors, had several surprise meetings with dolphins near their home on the coast of New Zealand. They decided to explore human/dolphin contact initiated by dolphins. In this journal-like book, Doak describes the work they did, dubbed Project Interlock, operating out of their Polynesian catamaran. The book has an insert of color pictures, showing the catamaran, the study areas, and Jan in the dolphin-suit she devised; there also are many underwater shots of the dolphins themselves.

***Volcano Weather: The Story of 1816, the Year without a Summer* by Henry Stommel and Elizabeth Stommel. 1983. Seven Seas Press, Newport, R.I. 177 pp. $15.00.**

The history of the eruption of Mount Tambora (on Sumbawa in the Indonesian Islands) in the spring of 1815. This extremely powerful explosion is said to have sent more dust into the atmosphere and obscured more sunlight than any other volcano from 1600 to the present. Its immediate effects included violent whirlwinds, huge lava flows, and, on Sumbawa, the death of all but 26 individuals in a population of 12,000. One year later, New England and northern Europe experienced an extremely cold summer, harvest failure, famine, and disease. The authors describe Tambora's eruption, then devote the bulk of the book to the phenomena that ensued. Finally, they analyze what is known about the relationship between volcanoes and weather.



***Graven by the Fishermen Themselves: Scrimshaw in Mystic Seaport Museum* by Richard C. Malley, 1983. Mystic Seaport Museum, Inc., Mystic, Conn. 155 pp. $16.00.**

Books Policy

Oceanus welcomes books from publishers in the marine field. All those received will be listed and a few will be selected for review. Please address correspondence to Elizabeth Miller, editor of the book section.

Mystic Seaport has an extensive collection, about 800 pieces, of scrimshaw. In this book, the major types of pieces and design styles found in the Mystic collection are examined and discussed. Excerpts from many diaries and journals reveal the personal significance of the items. The tools and techniques of scrimshaw are explained, and the history of the Seaport's collection chronicled; other chapters are about decorative and functional scrimshaw and scrimshaw collecting today.

***Oceanography: The Present and the Future,* Peter G. Brewer, ed. 1983. Springer-Verlag, New York, N.Y. 392 pp. $39.80.**

A companion volume to *Oceanography: The Past* (1982), the essays in this volume address the current status and future trends of oceanography. Topics covered range from molecular processes, planktonic community structure, and experiments with free-swimming fish, through circulation and productivity studies, to global-scale oceanography. The final section, The Human Scale, covers education, communication, ocean energy, aquaculture, and changes in global biogeochemistry.

***Jane's 1982-83 Naval Review,* Captain John Moore RN, ed. 1982. Jane's Publishing Company, Ltd., Science Books International, Inc., Boston, Mass. 160 pp. $15.95.**

In this book, nine distinguished contributors from three countries (England, the Netherlands, and the United States) write on topics currently important in naval defense. These range from debating naval security to discussions of future hull forms, marine fighting men, the Falklands war, and the Chinese navy. According to the editor, the review "offers a number of suggestions about the way things may go in the future."

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subjects is presented here, including the U.S. oceanographic experience in China, ventilation of aquatic plants, seabirds at sea, the origin of petroleum, the Panamanian sea-level canal, oil and gas exploration in the Gulf of Mexico, and the links between oceanography and prehistoric archaeology.

The Coast, Vol. 23:4, Winter 1980/81 — The science and politics of America's 80,000-mile shoreline.

regional councils, and the complex boundary dispute between the U.S. and Canada. Other articles deal with the electromagnetic sense of sharks, the effects of tritium on ocean dynamics, nitrogen fixation in salt marshes, and the discovery of animal colonies at hot springs on the ocean floor.

Sound in the Sea, Vol. 20:2, Spring 1977 — The use of acoustics in navigation and oceanography.

Issues not listed here, including those published prior to Spring 1977, are out of print. They are available on microfilm through University Microfilm International; 300 North Zeeb Road; Ann Arbor, MI 48106.

A Valuable Addition to Any Marine Science Library

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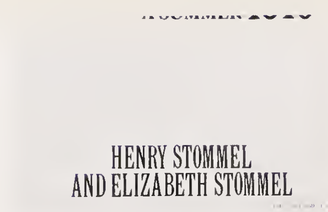

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WOODS HOLE OCEANOGRAPHIC INSTITUTION
1930

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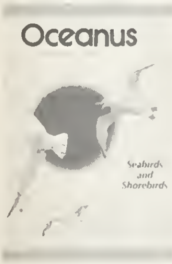

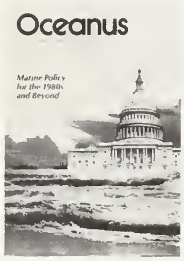

Seabirds and Shorebirds, Vol. 26:1, Spring 1983 — Many bird species play important roles in marine ecosystems. This issue contains articles on the feeding methods, breeding habits, migration, and conservation of marine birds. Other features include articles on the National Marine Sanctuaries Program and the 2-year ban on radwaste dumping by foreign nations.

Marine Policy for the 1980s and Beyond, Vol. 25:4, Winter 1982/83 — This issue examines the role of government in human activities affecting the sea. Each author makes recommendations for the future. The articles focus on the problems of managing fisheries, the controversy over dumping wastes in the oceans, the lack of coordination in United States Arctic research and development, military-sponsored oceanographic research, the Law of the Sea, and the potential for more international cooperation in oceanographic research.

Deep Ocean Mining, Vol. 25:3, Fall 1982 — Eight articles discuss the science and politics involved in plans to mine the deep ocean floor.

General Issue, Vol. 25:2, Summer 1982 — Contains articles on how Reagan Administration policies will affect coastal resource management, a promising new acoustic technique for measuring ocean processes, ocean hot springs research, planning aquaculture projects in the Third World, public response to a plan to bury high-level radioactive waste in the seabed, and a toxic marine organism that could prove useful in medical research.

Oceanography from Space, Vol. 24:3, Fall 1981 — Satellites can make important contributions toward our understanding of the sea.

General Issue, Vol. 24:2, Summer 1981 — A wide variety of subjects is presented here, including the U.S. oceanographic experience in China, ventilation of aquatic plants, seabirds at sea, the origin of petroleum, the Panamanian sea-level canal, oil and gas exploration in the Gulf of Mexico, and the links between oceanography and prehistoric archaeology.

The Coast, Vol. 23:4, Winter 1980/81 — The science and politics of America's 80,000-mile shoreline.

Senses of the Sea, Vol. 23:3, Fall 1980 — A look at the complex sensory systems of marine animals.

A Decade of Big Ocean Science, Vol. 23:1, Spring 1980 — As it has in other major branches of research, the team approach has become a powerful force in oceanography.

Ocean Energy, Vol. 22:4, Winter 1979/80 — How much new energy can the oceans supply as conventional resources diminish?

Ocean/Continent Boundaries, Vol. 22:3, Fall 1979 — Continental margins are being studied for oil and gas prospects as well as for plate tectonics data.

Oceans and Climate, Vol. 21:4, Fall 1978 — *Limited Supply only.*

General Issue, Vol. 21:3, Summer 1978 — The lead article here looks at the future of deep-ocean drilling. Another piece, heavily illustrated with sharply focused micrographs, describes the role of the scanning electron microscope in marine science. Rounding out the issue are articles on helium isotopes, seagrasses, paralytic shellfish poisoning, and the green sea turtle of the Cayman Islands.

Marine Mammals, Vol. 21:2, Spring 1978 — Attitudes toward marine mammals are changing worldwide.

The Deep Sea, Vol. 21:1, Winter 1978 — Over the last decade, scientists have become increasingly interested in the deep waters and sediments of the abyss.

General Issue, Vol. 20:3, Summer 1977 — The controversial 200-mile limit constitutes a mini-theme in this issue, including its effect on U.S. fisheries, management plans within regional councils, and the complex boundary disputes between the U.S. and Canada. Other articles deal with the electromagnetic sense of sharks, the effects of tritium on ocean dynamics, nitrogen fixation in salt marshes, and the discovery of animal colonies at hot springs on the ocean floor.

Sound in the Sea, Vol. 20:2, Spring 1977 — The use of acoustics in navigation and oceanography.

Issues not listed here, including those published prior to Spring 1977, are out of print. They are available on microfilm through University Microfilm International; 300 North Zeeb Road; Ann Arbor, MI 48106.

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